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GEOPHYSICS

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CONTENTS

Evaluation of New Geophysical Methods	*W. M. Rust, Jr.*	329
The Review and Analysis of Seismic Data	*E. D. Alcock*	338
Early Seismic Discoveries in Oklahoma	*B. B. Weatherby*	345
The Magnetic Field Over Igneous Pipes	*Victor J. Blum, S.J.*	368
Gravity and Magnetic Investigations at the Grand Saline Salt Dome, Van Zandt Co., Texas	*Jack W. Peters and Albert F. Dugan*	376
The Narrow-Band Resistance-Coupled Amplifier	*Laurence G. Cowles*	394
The Relative Abundance of the Carbon Isotopes in Petroleum	*S. S. West*	406
Preparation of Manuscripts for Publication in *Geophysics*	*L. L. Nettleton*	421
Foreign Geophysical Activities in 1944-45		429
Discussions and Communications		432
Patents		433
Publications Received		441
Contributors		442
Memorial		
Billy E. Richards	*Cecil E. Reel*	444
The Society Round Table		
Membership Applications Approved for Publication		446
The Fifteenth Annual Meeting of the Society of Exploration Geophysicists		448
Papers Presented or Read by Title at the Technical Sessions of the Fifteenth Annual Meeting		449
Minutes of the Annual Business Meeting		457
Officers for the Year Ending April, 1946		458
Annual Report of the Secretary-Treasurer of the Society of Exploration Geophysicists		460
Pacific Coast Meeting		462
Personal Items		463

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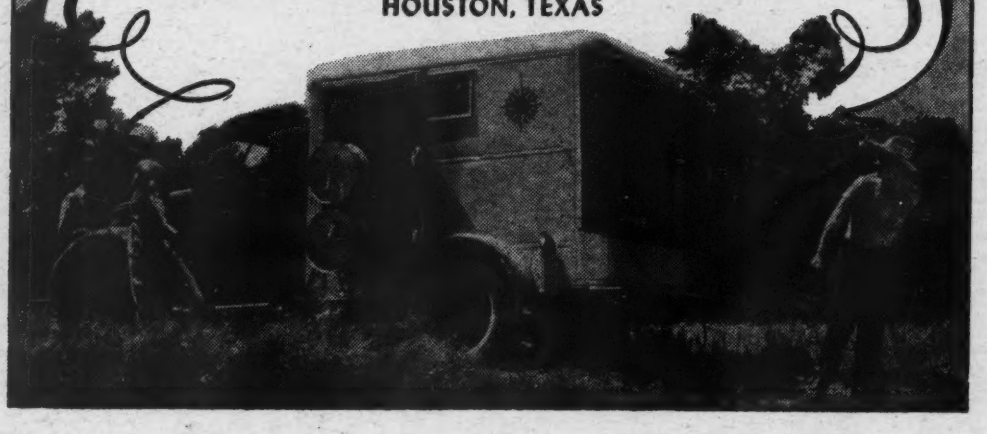

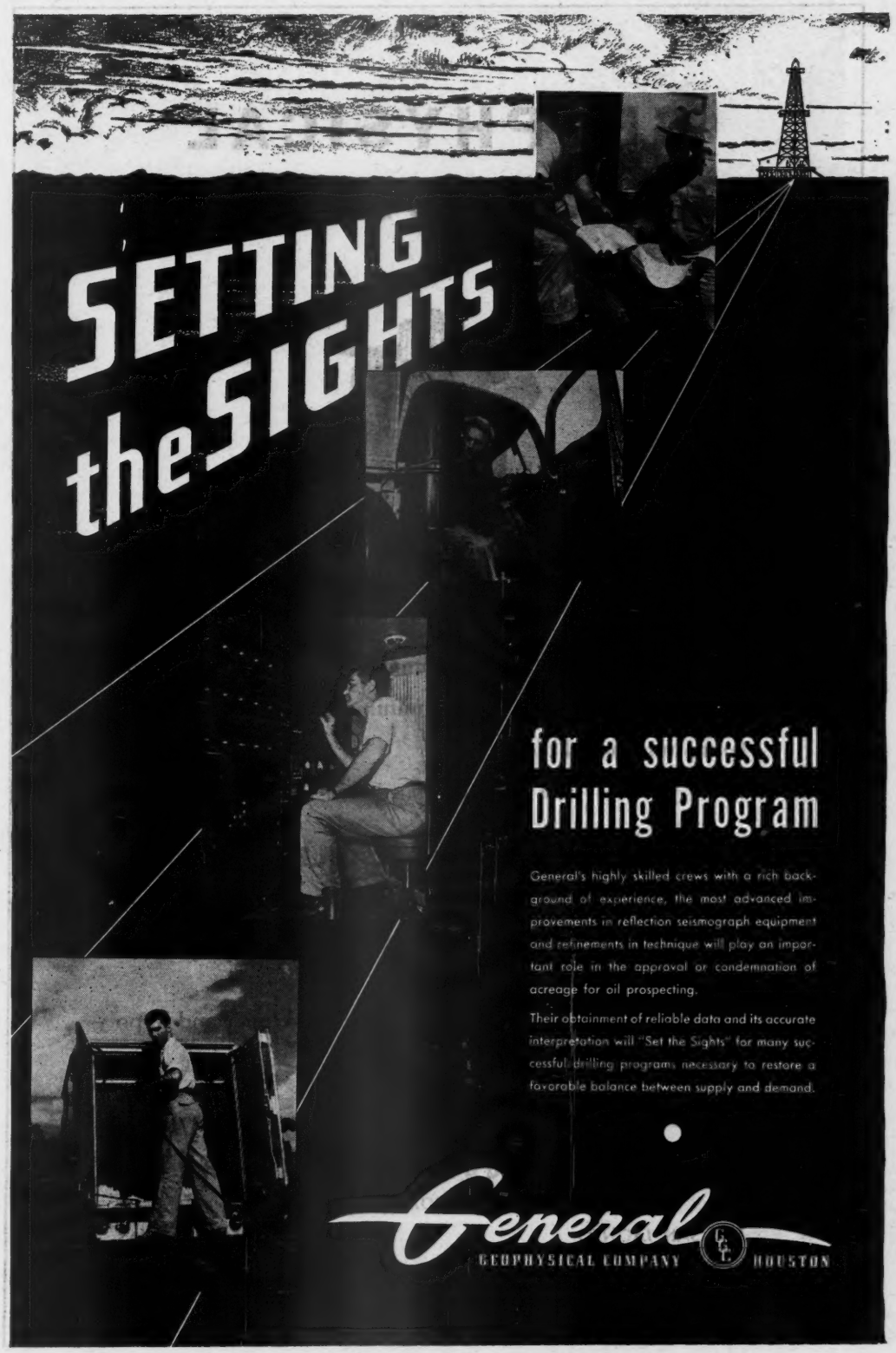
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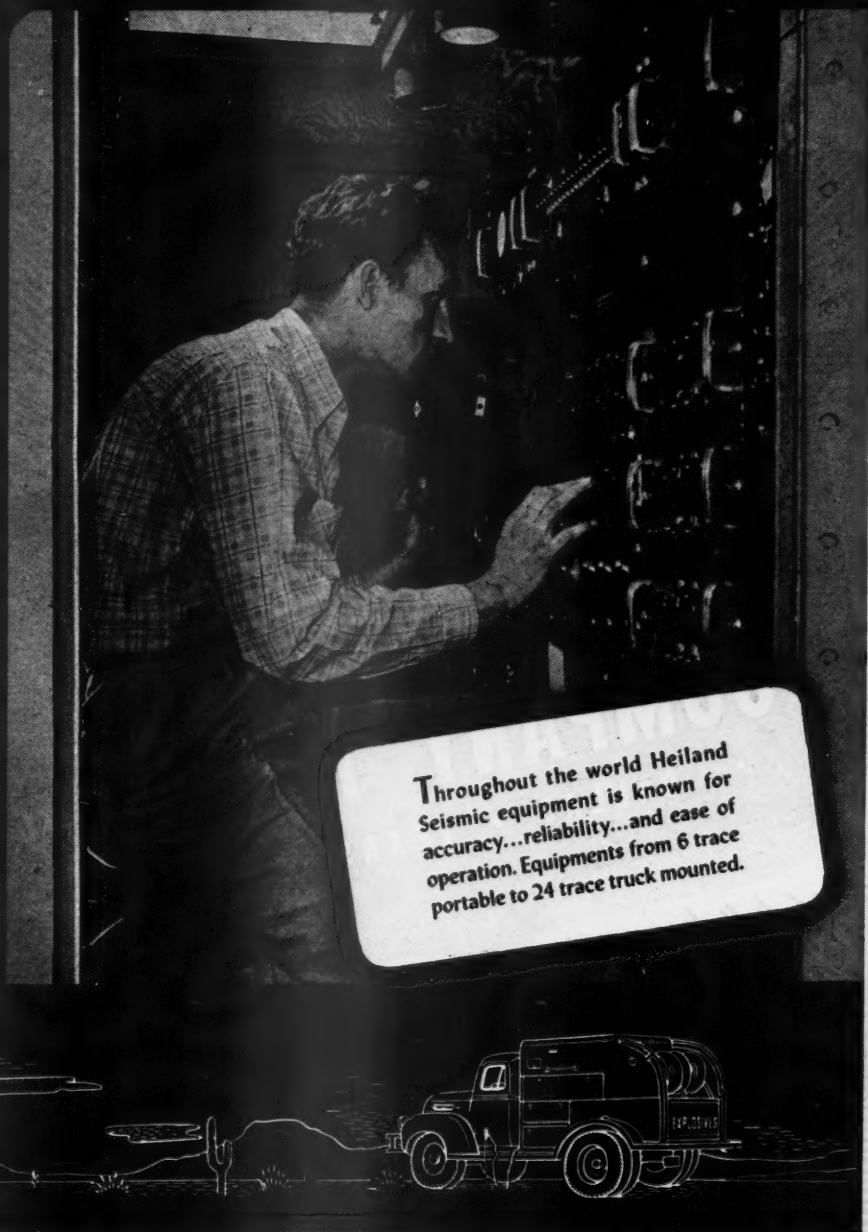

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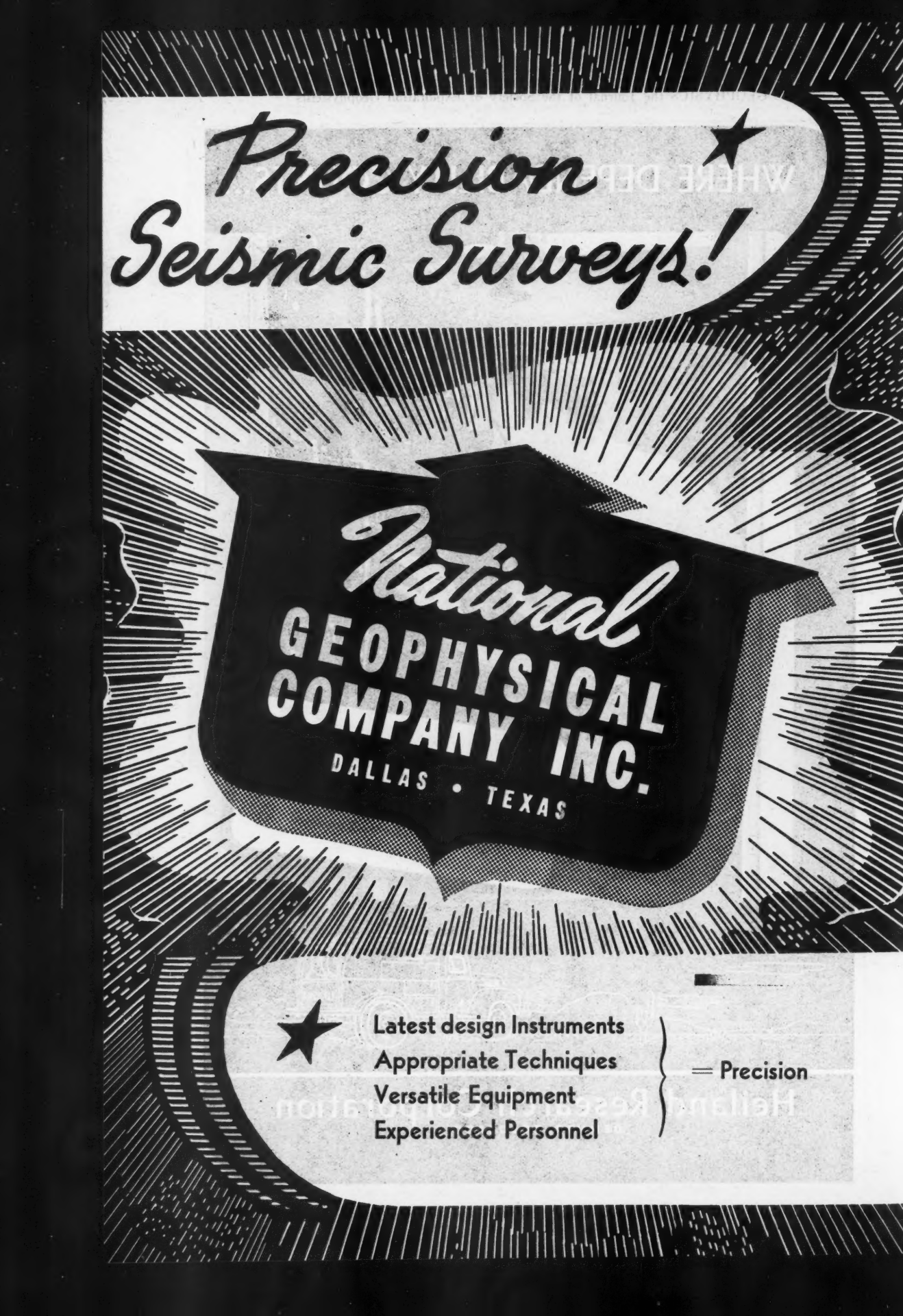
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Geophysical Instrument Company 9
Geophysical Service, Inc. ..*Outside back cover*
Geotechnical Corporation 26
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Harrison Equipment Company 6
Heiland Research Corporation 7
Hercules Powder Company 17
Independent Exploration Company .....
.....*Inside front cover*
Keystone Exploration Company 19
Lane-Wells Company 22
Mayes-Bevan Company 21
National Geophysical Company 8
North American Geophysical Company .. 28
Pancro Mirrors, Inc. 4
Petty Geophysical Engineering Company . 23
Robert H. Ray, Inc. 31
Rogers-Ray, Inc. 30
Ruska Instrument Corporation 29
S. A. Scherbatskoy 35
Schlumberger Well Surveying Corporation 27
Seismic Explorations, Inc. 16
Seismograph Service Corporation .....
.....*Inside back cover*
Southern Geophysical Co. 41
Torsion Balance Exploration Company .. 42
United Geophysical Company 39
Wallace & Tiernan Products, Inc. 3
Western Geophysical Company 24

PROFESSIONAL CARDS

Joseph L. Adler 11
Chester F. Barnes 14
Roland F. Beers 11
Thomas J. Bevan 13
Hart Brown 13
J. H. Deming 13
H. M. Evjen 12
John A. Gillin 12
T. I. Harkins 12
Sidon Harris 14
C. A. Heiland 12
J. O. Hoard 12
Leo Horvitz 12
John S. Ivy 11
J. C. Karcher 11
H. Klaus 12
Theodore Koulomzine 13
Tom D. Mayes 13
E. V. McCollum 14
Haydon W. McDonnold 13
George D. Mitchell, Jr. 14
Leonard J. Neuman 14
W. W. Newton 11
H. B. Peacock 11
J. C. Pollard 13
Robert H. Ray 13
F. F. Reynolds 13
E. E. Rosaire 11
Henry Salvatori 12
James L. Sauls, Jr. 14
S. A. Scherbatskoy 14
Joseph A. Sharpe 14
Joshua L. Soske 12
E. D. Williams 12
John H. Wilson 11
H. M. Zenor 14
Charles C. Zimmerman 13

Society of Exploration Geophysicists

Announcement is made of the appointment of a new Business Manager for the Society to succeed J. F. Gallie, whose other duties have forced his resignation. Editorial matters, as heretofore, will be handled by Dr. L. L. Nettleton, P. O. Box 2038, Pittsburgh 30, Pennsylvania. All other correspondence should be addressed to the attention of

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VOLUME X JULY, 1945 NUMBER 3

GEOPHYSICS

A Journal of General and Applied Geophysics

EVALUATION OF NEW GEOPHYSICAL METHODS*

W. M. RUST, JR.

INTRODUCTION

Last March when you did me the honor of selecting me as President, I hoped I would have the privilege in my Presidential Address of telling part of the story of the contributions of geophysicists to the war effort, and of attempting some prophecies concerning the contributions of the war to geophysicists' future prospecting efforts. For a time last fall, official optimism reached the point where it seemed that it would be possible to secure the release of some of the story; however, in December, I realized that someone else would have that pleasure. But, in looking forward to the day when we can turn away from our wartime activities, I have had my interest rekindled in an old problem, a problem which, with our present prospecting organizations, is the mutual responsibility of geophysicists, geologists and management. It is the problem of evaluating proposed new geophysical prospecting procedures and the somewhat simpler but still extremely difficult problem of evaluating modifications of existing methods.

We all remember the anguished cry that only the widespread adoption of new discovery methods could stop the distressing decline of discovery rate. Yet we know what happened when the problem of inadequate discoveries was made more acute by an unprecedented increase in production to oil the war. The number of seismograph crews reached an all-time high. The number of gravity crews reached an all-time high. But what of the crews using new or unconventional methods? Why are they conspicuous for their rarity? You know the

* Presidential Address, Society of Exploration Geophysicists, Tulsa, Oklahoma, April 4, 1945.

answer. Wisely or foolishly, we were afraid to use them when the heat was on.

I wish that my title, "Evaluation of New Geophysical Methods," actually meant that I was offering an evaluation of a number of new geophysical methods. Unfortunately, at the moment, there is a dearth of proposed methods, sound or unsound. The causes of this scarcity are well known and will end with the war. The unparalleled demand for technical men in the development, design, manufacture and use of instruments of warfare, has not only drawn the time and thought of nearly all of our research men and many of our operating men but has also turned the attention of free lance inventors, as well as crackpots, away from the ever-alluring problem of getting rich quick by discovering the answer to the problem of finding oil. This is natural. The problems of war have the obvious appeal of patriotism and, equally important, the stimulus of new and exciting approaches, as typified by radar.

But the war has not dried up the stream of oil finders' dreams; it has only dammed it up. War has emphasized the vital role petroleum plays in modern life. Over half of the tonnage of war material shipped overseas is made of petroleum products. Moreover, the pinch of gasoline and fuel oil rationing in this country has brought the problem home in a very direct and personal way. Everyone knows we must have an abundance of oil. It has also been widely stated that our oil-finding effort is not too satisfactory. Even before the war, we were told by many authorities that our consumption of petroleum was outstripping discoveries at an alarming and rapidly increasing rate. The enormously increased demand for oil brought on by the war and the diversion of the efforts of many men from prospecting, have obviously made the problem even more serious.

It is certain that the rewards, which this situation promises the fortunate inventor, coupled with the availability of wartime technological miracles, such as some of the gadgets which drove the Nazi submarines to cover, radar and other still-secret developments, will result in a stream of proposals of new geophysical methods and modifications of old methods. Radar may well replace the witch-hazel fork. When this flood comes, from our own men and from outsiders, we will be faced with a two-fold problem of extraordinary difficulty. First, we must recognize and adopt any proposal of real merit. Second, we must condemn, with the least possible expenditure of money and effort, all proposals which have no real merit.

STATEMENT OF CRITERIA

Here I hasten to make my second confession. Not only have I no new methods to evaluate for you today, I also have no sure and simple system of evaluation to propound! I hope, however, that it may prove helpful, or at least interesting, to discuss a few phases of the problem. Let me first state five criteria which a usable geophysical prospecting method must satisfy. I am willing to make the categorical statement that any method which fails to satisfy these criteria, properly interpreted, is of no value. At first sight, these criteria may seem so obvious that discussion is unwarranted. Perhaps. But the first three are fairly simple to apply and will dispose of a high percentage of crackpots. The last two, which are intimately related, are the ones which require skill, patience and a touch of clairvoyance, to apply with certainty.

First, the method must involve physical measurements of some property of the earth. I use the term "physical" here to distinguish from "psychical" and include chemical, biological and so on.

Second, the measurements must give reproducible results. The term reproducible will require some explanation.

Third, the process must be able to compete, on the basis of economics, with existing methods. This involves both the cost of operations and the value of the results.

Fourth, and this is almost a restatement of our problem—the method must have a significant relation to the occurrence of oil.

Fifth, the method must have a teachable interpretation.

DISCUSSION OF INDIVIDUAL CRITERIA

A consideration of the individual criteria will show that they are somewhat less obvious than appears at first glimpse. The first criterion, that the method be based on physical measurements of some property of the earth, seems one that could cause little argument. I would like to extend this criterion to require that the physical property involved be identifiable. This would, I believe, exclude the wiggle-sticks and unique instruments, which, for reasons unknown to the discoverers, give certain reactions when directly over oil or gas. Even if some Yogi has psychical powers that enable him to locate oil or if by some queer and unknown chain of events, my watch decides to stop whenever I cross a pool of oil, these remain isolated phenomena and unless the laws that govern them can be determined and, in the first case, our seismograph computers taught Yogiism, and, in the second, our instrument makers taught to duplicate my watch, neither can form

the basis of a new geophysical method. Under extraordinary conditions we may be willing to waive the requirement that the physical property be identifiable and insist only that a definite series of manipulations leading to a numerical result be followed. We twist the knobs on a little black box according to definite rules and read a scale. If I can be convinced that the resulting scale reading is actually a function of the location where the measurements are made and satisfies my second criterion, I may begrudgingly admit that it is a physical measurement of some as yet unidentified property of the earth, but until I invent a name for the property and discover some of the laws it obeys, I will remain unsatisfied and suspicious.

Suppose now we have a device which gives a physical measurement in this sense. It is of no value unless the elementary data which it gives at a series of stations in an area can be repeated with a sufficiently high degree of accuracy or unless repeatable secondary values can be obtained from these primary data by straightforward computations calling for a minimum of personal judgment. An example of the latter type is given by a magentometer survey where corrections must be made for diurnal variation. This criterion is not too simple to apply. No physical measurement can be made with absolute accuracy. If enough significant figures are retained, repeated readings will always differ. This is often particularly pronounced in geophysical measurements. We must, therefore, decide what we mean by a sufficiently high degree of accuracy of repeated measurements. The error in repetition at an individual station must be a fairly small fraction of the difference between values at stations on and off of the anomaly. Not only must the measurement at individual stations be reproducible but the anomalies obtained in an area by occupying two different but overlapping sets of stations should practically coincide. The data should be smooth in the sense that the variations observed over an area containing an anomaly interpreted as indicating an oil field, should be much greater than the variations observed when the same number of stations are crowded into any small portion of the area. It is true that a method which is basically sound may fail to meet this criterion in the course of any one trial because of instrumental difficulties. But this is a problem for the developer of the method, not the evaluator. Until such difficulties are largely overcome or at the very least readily identifiable, the process should not be called a geophysical prospecting method.

With satisfactory cooperation from the advocates of the method, these two criteria can be applied with reasonable assurance that

fairly definite answers to them will be obtained without an excessive expenditure of time, money or effort. The principal requirement, other than careful, conscientious work, is that a sufficiently large region be covered to give both normal and anomalous areas. A method which fails to satisfy these two criteria certainly cannot be used as a practical prospecting method; at best, it may serve as the basis for further research. On the other hand, it is easy to think of methods which satisfy these criteria which are not useful prospecting methods. As a concrete example, I can mention measuring the distance to the nearest hard-surfaced road. Incidentally, it might surprise you how well this method succeeds in finding oil fields!

Before we turn to the difficult and somewhat speculative fourth and fifth criteria, let us look at the reasonably simple third criterion—the method must be economically competitive with existing methods. That is, it must give valuable results not given by other methods at comparable cost. This may be true if it finds oil not found by other methods, even though it may fail to find some oil they can find. It is not necessary for a new method to make all existing methods obsolete in order for it to deserve acceptance. Each individual case must be considered on its own merits. We can, however, determine some general limits. The cost per acre certainly must be less than the cost of drilling closely controlled wells to the maximum effective depth of the method and closely enough spaced so that no commercial deposit of oil or gas could be missed. It seems safe to assume that no geophysical method will give more direct and valuable data than a properly drilled wildcat. At the other extreme, a new method cannot compete with one of the established methods which gives equivalent information at a comparable cost per acre. Within these wide limits, the cost and value of the method must be weighed against one another and against those of other methods by intelligent guessing. In many specific cases, there may be room for arguments, but frequently the answer will be obvious after a moderate amount of study.

The fourth criterion, that the method must give information significantly related to the occurrence of oil will in most interesting cases be difficult to apply. I define the term "significantly related" pragmatically. I will say that a method gives information significantly related to the occurrence of oil, if the information is successful in finding oil, when used to guide a program of leasing and drilling with the same intelligence and confidence that the information from reflection seismograph work is now used.

Two approaches to the application of this criterion are useful. The

first is the theoretical. If the theory of the method is well developed and if numerical data on the variation of the relevant physical properties on and off of anomalies are available, it is possible to give a mathematical "Yes" or "No," if the calculations can be carried out without the necessity of introducing approximations which vitiate the conclusions. Three substantial "If's"! Thus, it is possible to say with complete assurance that no refinement of surface gravity methods will permit one to determine the presence or absence of oil in the subsurface. Likewise, it is possible to say that radar methods, depending on the transmission of ultra-high-frequency electromagnetic waves through thousands of feet of soil will not find oil in place. There is, however, a serious danger in theoretical studies of reaching the wrong conclusion by starting from false assumptions. Everyone knows the classic story of the major company that refused to use the reflection seismograph for five years after its introduction because an internationally known physicist, retained by them as a consultant, proved mathematically that the method was unsound. However, even where a final and definite answer cannot be obtained from a theoretical investigation of the method, such a study is very useful both in applying the method and in guiding an empirical study by suggesting possible strong and weak points of the method. Whenever possible, it should be part of the evaluation program.

The second approach is the empirical and statistical. A thorough empirical study is a long and costly process. Because of the nature of the technical problems involved, the direct responsibility whould be borne by a geophysicist, but because geological data, and often information on future drilling programs, are needed, the geologists are closely involved. Likewise, because the program may well involve very substantial expenditures before a final decision is reached, full support from management is essential.

One of the first and most important steps in an empirical evaluation is the selection of the types of areas and the actual areas to be studied. It is frequently necessary to select a number of different areas for study before condemning a method. Suppose the first tests of the reflection seismograph had been in certain parts of West Texas! Or, suppose the early refraction and gravitational work had not been in salt-dome country! A number of systems for selecting the trial areas has been suggested. A popular and useful system is to select areas where rather comprehensive data, from other geophysical methods and from wells are already available. This system has the advan-

tage that the results of the proposed method can be compared with those of other methods very quickly. There are, however, some other rather serious objections to this system. For example, the physical nature of an oil field is changed in many respects during the development process. This may well result in anomalies on the oil fields which were not there before the development. Or, conversely, it may obscure a legitimate anomaly which could readily have been found before development. Nor is this all. The interpreter is very apt to be influenced, one way or the other, by his knowledge that an oil field is there. Even if he is not, any one who examines his work will be inclined to discount the anomalies which occur on oil fields. Thus, both physical and psychological factors conspire to detract from the value of the areas which are occupied by oil fields. The same thing is true, to a lesser extent, of dry holes. Even if there are no oil fields or dry holes, there is some fear that the results, particularly if an important element of judgment is involved, may somehow be colored by the information already in hand. If an area is selected where little drilling has been done, but where the geophysical data are considered good, useful results are obtained where the new and old data agree; but when they disagree, one is in a dilemma. If the old method is assumed to be perfect, there is little point in trying the new method. But if it is admitted that the old method is fallible, nothing is added to our knowledge of the new method. This system, however, is particularly useful in studying methods for which very specific claims have been made. For example, a method which is supposed to locate the edge of production by measurements along a single profile may be quickly disposed of in the woods on the edge of any one of many oil fields. Or, an electrical method which is said to be insensitive to shallow variations may readily be checked by a line across a known shallow anomaly. Such spot tests are necessarily negative in nature. They weed out some unsound methods but do not prove the soundness of the methods which they fail to condemn. In using spot tests, one runs the risk of condemning a useful method because its promotor was overenthusiastic.

Another system, which has much to recommend it, is to work fairly large areas around locations of wildcat wells which are to be drilled in the near future. This avoids most of the difficulties of the preceding system. It requires much more time and is therefore feasible only for very promising methods. It may be argued that this system gives some advantage to the method under investigation since wildcats are presumably drilled only in areas which seem favorable. This

difficulty can be minimized by working a large enough area around each wildcat.

A third system, which on a purely technical basis is the most desirable but which is very expensive if the method turns out to be unsound, is to select a number of rather large areas, prospect them with the proposed method and then drill the anomalies. This gives a very direct answer as far as each particular area is concerned. A disadvantage of this system is that if the method fails in the first area tried, it is very likely to be condemned even though it might well have succeeded in the next area.

Whatever procedure is used in attempting an empirical evaluation of a proposed method, there is a grave danger of demanding an unnecessary degree of perfection. Because of the limitations of the present prospecting methods, a new method could prove to be very useful and yet have a fairly high ratio of failures to successes. According to Lahee, of 596 wildcats drilled primarily on seismograph data in 1943, only 123 were producers. Thus, a new method, which gave one discovery out of each five wildcats, might be a serious competitor of the seismograph in determining locations of wildcats. This contrasts rather strongly with the scale we are likely to use in evaluating a new method empirically. Depending upon such factors as the "reasonableness" of the method and our personal hunches, we are apt to demand that the method find 75 to 100 percent of known prospects in an area and that from 50 to 100 percent of the prospects it finds, on which we have other information, should be either oil fields or at least suitable traps. On the other hand, if we lower our standards to a somewhat more reasonable ratio of successes to failures we run into trouble with coincidences and the possibility of those secondary factors which result from the development of oil fields, such as my earlier example of hard-surfaced roads.

By my fifth criterion, the method must have a teachable interpretation, I simply mean that it must be possible for a trained interpreter to derive from the primary data, given by the method, information which is usable in the search for oil and that the process used in deriving this information must be one which may require intelligence, experience and judgment but not guesses or arbitrary choices. Two skilled interpreters should usually arrive at very similar answers. While I have placed this criterion fifth, it is so intimately tied in with the fourth, that the two must be studied simultaneously. An interpretation which satisfies this criterion will very likely combine an appli-

cation of the theory of the method with geological knowledge concerning the nature of the probable oil traps in the region under investigation. This is not absolutely necessary. The interpretation may be based entirely on an empirical correlation between certain observed phenomena and the occurrence of oil. But such interpretations are usually unsatisfying because they frequently involve too strong an element of personal judgment or even intuition and because it is difficult to amass sufficient trustworthy data to substantiate the correlation.

CONCLUSIONS

My principal desire in this discussion has been to call your attention to the difficulty of the problems involved in evaluating a proposed geophysical method. I hope I have made it clear that this is a problem which demands the most careful and thoughtful attention. It is a problem that can be solved correctly only by teamwork between geophysicist, geologist and management. Each must contribute his full share and have his full responsibility. The contact between the members of the team must be intimate and each must have the confidence of the others. This is not a problem which can be solved by the haphazard methods that have been used in the past. Nor is it a problem that can be solved by oratory or debate. Unless you are prepared to spend the time and money justified by the worth of a new prospecting tool, you will do yourself a service by not wasting your money and effort and the industry a service by not confusing the picture.

In conclusion, I wish to make it clear that while my topic has called for emphasis on possible new methods, I am neither too optimistic about their possibilities nor too pessimistic concerning the remaining possibilities of our present methods. I expect considerable improvement in our conventional instruments and techniques. But let me close with a word of warning, the future progress of geophysics cannot come entirely from technical advances, either in new methods or improvements of old methods. Much of it must come from advances in the use of the minds of geophysicists.

THE REVIEW AND ANALYSIS OF SEISMIC DATA*

E. D. ALCOCK

ABSTRACT

It is proposed that separate departments be established for the review and analysis of seismic data. The functions of these departments would be to review and submit independent interpretations of current seismic data, to review old seismic data in the light of new geological and geophysical developments, to compile and prepare regional seismic maps and to investigate areas in which seismic and geological data do not conform. This paper discusses the benefits to be expected from such a program, the source of man power, and the costs.

The necessity for increased exploration at the present time has produced a demand for seismic work that far exceeds the number of available crews. In normal times this situation would be rectified by the formation of new crews. Wartime shortages in the critical materials needed for new equipment and instruments and the lack of man power limit the number of crews which can be formed; hence, we must look elsewhere for a solution to the problem. If a new low-cost exploration method were to appear, I have no doubt that it would cause tremendous excitement in the exploration fraternity. Furthermore, if it could be demonstrated that the new method had produced concrete results in a number of cases, the method would be given an immediate trial by the industry as a whole.

Let me now describe a program of exploration which in its entirety is new and economical. This program proposes a separate department for the review and analysis of seismic data. The functions of such a department would be:

I. To review and submit an independent interpretation of current seismic data
II. To review old seismic data in the light of new geological and geophysical developments
III. To compile and prepare regional seismic maps
IV. To investigate areas in which seismic and geological data do not conform

It may be objected that such a program is not new in that some companies are preparing independent interpretations of current data and sporadically reviewing old seismic data. I maintain, however, that a well organized and coordinated program for the performance of all of

* Read at the Tulsa and Dallas meetings at the Society, 1945.

the functions outlined above would be an innovation and one which should pay handsome returns on the money invested.

Let us now consider some of the benefits of such a program.

I

INDEPENDENT INTERPRETATION OF CURRENT DATA

The current seismic work would be checked and independently interpreted. It is customary in the organization of most seismic crews for the party chief to be the interpreter and executive officer of the crew. The time that the party chief has available for the study of the records is of necessity interrupted in order to attend to the various field problems as they arise. This time, therefore, is not nearly as efficacious as it would be if he were able to spend it in a continuous period of record study. It therefore should be beneficial to have an interpretation made by an independent interpreter who is not limited in the time which he can devote to the record study and who is free from the troublesome problems of running the crew. Since the interpreter is not required to attend to executive details, it is estimated that his productive capacity for interpretation would be much higher than that of the party chief, and that he should be able to handle the current production from several crews.

Seismic results, like most geophysical results, have to be interpreted before they have any geological significance. Physical measurements are taken, and from these data a deduction is made as to the subsurface conditions which produced the data. This process of interpretation is not an exact science but an individual affair, and the validity of the interpretation will depend to a high degree upon the individual, his prejudices, his skill, and his experience. During the course of the interpretation problems will arise which the interpreter must decide according to his individual opinion. It is quite possible that different interpreters of equal skill would decide differently at these points. In order to determine where such decisions have been made, it is necessary for the interpreter to study the records thoroughly. This cannot be done by merely reviewing the interpretation, since the first decision made generally prejudices any later decisions in that direction. It is presumed that the interpreters employed in the review work would have more skill and experience than the ordinary party chief. Hence, it would be of value to know where differences of opinion in regard to the interpretation could arise. Review of current work can be carried on contemporaneously with the shooting, which would re-

quire duplicate records, or immediately following the completion of the prospect. Both of these methods of reviewing the contemporaneous work have their advantages and disadvantages.

The first method, namely that of interpreting the work at the same time the survey is being conducted, has the disadvantages that duplicate records must be obtained, and that the reviewer does not have all the data from the area available at one time; therefore his work progresses by spurts from day to day. To offset this, however, the field crew has the benefit of the reviewer's guidance during the progress of the survey, and the method insures the securing of sufficient data to make an adequate interpretation by either the party chief or the reviewer. It also has the advantage that the reviewer is not influenced by the party chief's marking of the records. It is considered that this would be the best method for accomplishing this objective.

The second method, that of reviewing the work upon the termination of the prospect, has the advantages that duplicate records are not required and that all the data from the area are available so that the review interpreter can devote a continuous period of study to the interpretation. This is offset by the disadvantage, however, of the possibility of the reviewer's being influenced by the marked records, and the inability of the reviewer to obtain additional data to support his interpretation, should it be necessary. In either case, the review should not be carried on in a field office, but in an atmosphere free from field worries.

II

REVIEW OF OLD SEISMIC DATA

The old seismic data would be reviewed in light of new geological and geophysical developments. This is a very important function of the proposed review department and one which should, if well organized and coordinated with the geological staff, produce results that would not be obtained if the program were not in force. Since the inauguration of seismic exploration, a large amount of work has been done and a tremendous mass of data has been recorded and filed away. It should be stated that, in general, the original interpretation of these data was adequate in light of the geological and geophysical ideas existing at the time the data were recorded. Geological and geophysical ideas, however, change as added experience is acquired. Hence, a new interpretation may reveal attractive anomalies in view of present conditions which were either overlooked by the original

interpreter or not deemed worthy of consideration at the time the survey was conducted. Thus, any company which has an accumulated mass of seismic data has a new and fertile field for exploration. New geological developments, such as new producing horizons or changes in opinion as to the size of structure believed economical, would be the basis for a review of all the old seismic data in the area affected.

Let us now consider a concrete example. In the early days the East Texas basin was "shot" with the Woodbine horizon as the objective. The structures mapped with this horizon as the objective had to be of a certain magnitude before they were considered economically feasible. Later, a new producing horizon was encountered in the Paluxy zone, and apparently, from the results obtained to date, the size of structure necessary for Paluxy production is less than that for Woodbine production. If a program such as that proposed by the present article were in force, the discovery of such a new producing horizon would be the signal for a general review of all old seismic work in the area affected. Such a review would relieve the geological staff from the responsibility of remembering all the old prospects which were not worthy of consideration at the time the survey was conducted, and would automatically bring up all prospects for reconsideration in view of the new development. In addition, these prospects would be reinterpreted with the benefit of the added skill and experience of the reviewer. I am sure that all of us can recall cases where areas were "shot" in the past and dismissed as not worthy of consideration that have later developed into oil fields. A systematic program of review would insure against the overlooking of structures buried in the files of old seismic work.

The recognition of subsurface faulting from seismic data is an art that can only be acquired by experience, especially in areas where the direct correlation of reflections is uncertain. Therefore, the additional experience which the reviewer is presumed to have over the party chief should be of direct benefit. A reinterpretation of old data with the experience available at present frequently reveals faulting that was not observed in the original interpretation. That is not to say that today faults can be recognized from seismic data with any great certainty, but only that progress is being made. These faults may reveal productive possibilities where the accumulation is governed by faulting rather than by other structural closures.

In many cases the review of the old data will reveal leads which were not considered significant at the time the survey was conducted,

and hence were not "shot" in sufficient detail to insure a trustworthy interpretation. Such a review, however, would form the basis for additional shooting, and as such would be of value to the geological staff in outlining the future exploration program.

As time passes changes take place in the methods of geophysical interpretation. A systematic review would insure that structures which would benefit by such advances in geophysical interpretation were not forgotten. As examples of such advances, one could mention changes in weathering and elevation correction technique, new velocity information, detection of faulting evidence on the seismic records, etc.

To sum up the benefits from this review of old seismic data, we have:

1) The prime objective is to locate anomalies which were not revealed by the original interpretation, and to point up those anomalies which were not considered commercially profitable at the time the survey was conducted but which offer possibilities in view of current experience. With this in mind, the old data should not merely be checked, but should be completely reinterpreted with as nearly an independent viewpoint as it is possible for the interpreter to maintain.

2) In areas where new producing horizons have been discovered an effort should be made to prepare a map close to the new horizon where possible.

3) All available subsurface data should be reconciled with the new interpretation.

4) The data would be reinterpreted using the best velocity data available and the most appropriate interpretation technique.

5) Leads for future shooting would be brought to the attention of the geological staff.

III

THE COMPILING AND PREPARATION OF REGIONAL SEISMIC MAPS

The benefit of this function of the review department would bear the same relationship to geophysical work that the benefit derived from compiling and preparation of regional geological maps bears to the geological work. It is a function which cannot be left to untrained geophysicists, since the data will be the results of interpretations submitted by several interpreters using various techniques. In general, it will be necessary for the reviewer to reconcile these interpretations on some rational basis before they will conform. This will require considerable skill, knowledge and reinterpretation on the part

of the reviewer. Such a regional map should be of great value to the geological staff in its intelligent preparation of its future shooting program.

IV

INVESTIGATION OF SEISMIC DEFICIENCIES

In many areas the interpretation of the seismic data does not conform to the geological conditions as revealed by the drill. Such areas are usually dismissed with the comment, "The seismograph does not work here." This is certainly one viewpoint of the problem. However, a better viewpoint would be that these areas present us with a problem which, if solved, might lead to an improvement in our geophysical technique. By investigation of the areas where the interpretation of the seismic data and the geological conditions do not conform, we may be able to discover methods which would increase the accuracy of our present work. After all, the lack of conformity is in general not caused by errors in data, but by faults in our interpretation technique.

This function of the review department would essentially be research into the accuracy and dependability of our present geophysical interpretation technique and the development of new and improved techniques. Considerable time and money are spent on research work devoted to the development of improved instruments for the recording of the data; very little, however, has been spent for improvement in interpretational technique. Most of the men engaged in interpretation at present have little or no time to devote to the investigation of such nebulous suspicions as, for example, the possibility of correlating the character of a reflection to the geological character of a formation. Such problems could be adequately investigated by a department of this sort.

Let us now consider the problems which would be presented by such a program. The first problem which would arise under the wartime conditions existing at present is man power. Where would the men come from who would have the training and skill necessary for the performance of this work? Naturally one could not inaugurate the program in its entirety immediately, but I do believe that in time, if such a program were planned, skilled men could be found and employed for the work. It has been the history of the geophysical industry that it continually loses experienced interpreters to other industries. The main reason for such a loss of skilled men is the personal hardship and expense involved in the moving of their families from

place to place in the field. A review program offering jobs with fixed locations should enable the industry to retain some of these men and might induce some men now working in other professions to return.

The second problem of such a program would be the expense. If a cost analysis is made of seismic exploration, we find that a disproportionate part of the outlay is devoted to the mechanical recording of the data, and an extremely small percentage is devoted to the interpretation. I think a reasonable estimate based on current experience would be that less than ten per cent of the cost is devoted to the interpretation of the data. This would indicate, then, that the review work could be done at a figure which would be only ten per cent of that which would be required to resurvey the area. This estimate is probably high, since the productivity of an interpreter engaged solely in review work would be higher than that of a party chief who must devote a large part of his time to executive details. It would be folly to believe that such a review and analysis program would be as productive of new oil reserves as the original survey. I do believe, however, if one considers the relationship in the cost of both programs, that the review and analysis work would be economically profitable.

CONCLUSION

It is the purpose of this paper to suggest a new field of exploration, namely, that of the files of old records which have been recorded in the past. It is not intended in any way to criticize the quality of the work done in the past, but merely to point out that interpretational advances have been made since this work was originally done. It is believed that a review of the old work in view of our present knowledge would be productive of many new prospects. It is also suggested that it would be profitable to have the opinion of an independent interpreter of our current work.

The author wishes to express his thanks to the National Geophysical Company, Inc. for permission to publish this paper.

EARLY SEISMIC DISCOVERIES IN OKLAHOMA*

B. B. WEATHERBY[1]

ABSTRACT

Systematic seismic reflection shooting was begun on the Seminole Plateau of Oklahoma in 1927. In the beginning the results were somewhat undependable and well checks were disappointing. The various difficulties were gradually ironed out so that with the discovery of South Earlsboro in 1929 and the North Extension of Carr City and West Seminole in 1930, new impetus was given to the use of the method. The history of these discoveries together with maps and records show the measure of success obtained at that time.

Data on the Polo Field, discovered in 1931 and detailed in 1934, are compared with this early work.

While experimental work on the seismic reflection method was being carried on in various areas during the period from 1927–1930[2] it might be said that central Oklahoma, and more particularly the Seminole Plateau, was the proving ground for the seismic reflection method since it was here first developed to the point that several discoveries in rapid succession followed its use. Paradoxically this area was one of the simplest and at the same time one of the most difficult that could have been picked. It seemed simple because of the generally good quality of the reflections by virtue of which correlation difficulties were minimized. Actually, it was quite difficult because marked unconformities in the section, in many cases, gave rise to erroneous structural interpretations.

The geological section included several hard limestones, such as the Hunton and the Viola, which were excellent reflectors. The main producing horizons, the Wilcox sands, which produced oil on occasion when their porosity and structural position were favorable were only a few hundred feet below these reflectors. Fig. 1 is a typical well log of the Plateau area. It shows the position of the main reflecting limestone with reference to the productive Wilcox sands. Fortunately over a considerable portion of this region the Viola lime produced the dominant reflection and since it lay conformably over the Wilcox sands the mapping of the producing horizon was simplified. Unfortunately, how-

* Read at the Tulsa and Dallas meetings at the society, 1945.

[1] Geophysical Research Corporation.

[2] B. B. Weatherby, The History and Development of Seismic Prospecting, GEOPHYSICS, Vol. 5, No. 3, (July 1940), pp. 215–230.

ever, the Hunton and Mayes were not conformable with the Viola and Wilcox and frequently they, too, produced good reflections. No particular difficulty was encountered with the correlation, if all three of them happened to act as reflectors and there was a sufficient time interval between each impulse to separate them. On occasion, however, the reflections, instead of being sufficiently separated, actually overlapped, in which case a composite pattern was obtained, the character-

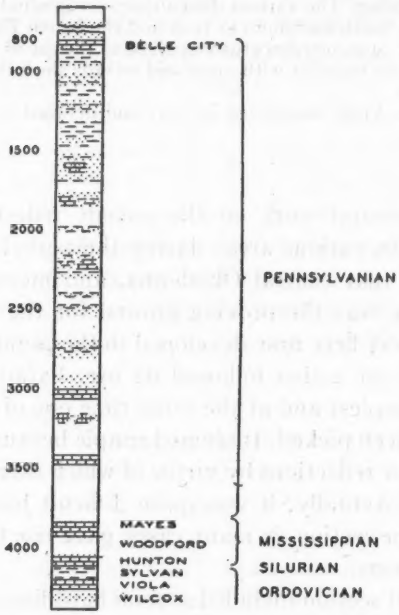

FIG. 1. Typical Well Log of Seminole Plateau Area, Oklahoma.

istics of which depended on the relative amplitudes and time intervals between the different reflections. Frequently, however, one of the three reflections either suffered a considerable loss in amplitude or on occasion disappeared. It was the seismologists' difficult problem to decipher these patterns and from them to determine what had happened to the different reflecting horizons.

Even in the relatively simple case of the single reflection there were difficulties to be overcome. One of the limes above the Viola, for example the Hunton, might, and on occasion did, produce a sufficiently outstanding reflection to blot out any effect from the limes below.

Since it was known that Hunton hills existed which had no structural counterpart in the Viola and Wilcox it was necessary to avoid the error of mapping Hunton topography and calling it Viola structure. This could only be accomplished by knowing which bed was producing the reflection. At that time experience had shown that wells with a Viola datum lower than −3200 generally encountered water in the first

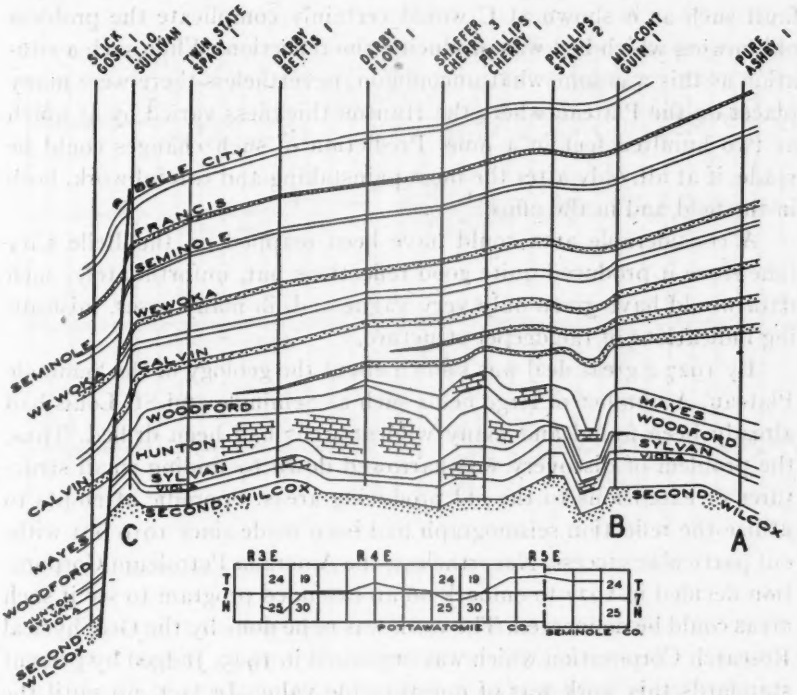

FIG. 2. West-East Cross Section, St. Louis and Pearson Pools, Seminole and Pottawatomie Counties, Oklahoma

Wilcox sand. Consequently it was highly desirable to predict not only the amount of closure on a Viola structure but also the absolute datum on that bed. Thus, it was necessary to know the velocity of the section quite accurately and it was further necessary to guard at all times against jumping from one reflecting horizon to another.

These difficulties can be clearly illustrated by reference to Fig. 2, which is a cross-section of the St. Louis Pool in Seminole and Pottawatomie Counties. Suppose, for example, in Fig. 2 between the points

A and B, where no Hunton was present, a single reflection from the Viola was obtained. At the point B the Hunton began to come into the section. It would be quite possible to jump to a Hunton reflection at this point, having the same datum as the Viola reflection immediately east of B. Thus, there would be no appreciable change in datum to indicate that a miscorrelation had been made, and an erroneous picture of the Viola would result between B and C. Moreover, crossing a fault such as is shown at C would certainly complicate the problem of knowing which bed was producing the reflection. While such a situation as this was somewhat uncommon, nevertheless there were many places on the Plateau where the Hunton thickness varied by as much as two hundred feet in a mile. Prediction of such changes could be made, if at all, only after the most painstaking and careful work, both in the field and in the office.

A considerable area could have been mapped on the Belle City lime since it produced quite good reflections but, unfortunately, such data would have given only very vague and, in many cases, misleading indications of the deeper structure.

By 1927 a great deal was known about the geology of the Seminole Plateau. A number of large fields such as Seminole and St. Louis had already been found and many wildcat wells had been drilled. Thus, the problem of discovery was narrowed down to finding small structures or extensions to the old producing areas. Sporadic attempts to utilize the reflection seismograph had been made since 1919 but without particular success. Nevertheless, the Amerada Petroleum Corporation decided in 1927 to embark on an extended program to see if such areas could be delineated. The work was to be done by the Geophysical Research Corporation which was organized in 1925. Judged by present standards this work was of questionable value. In fact, up until the fall of 1928, it should be considered mainly of an experimental nature although one or two structures had been indicated.

In early 1929 the method was under considerable fire. Seismic predictions made during 1927 and 1928 had been only partially confirmed by the wells drilled on the Plateau during this period. Doubt was expressed on a number of occasions as to whether the recorded pulses actually were reflections and if so whether they came from beds as deep as the Hunton and Viola. Consequently it was necessary to do something to revive the earlier optimism. Fortunately the opportunity to do this was presented in a program then in progress.

In central Kansas in the spring of 1929 a considerable area had

been mapped on the Cimarron anhydrite which varied in depth from three hundred to fifteen hundred feet. An example of the type of record obtained in this work is shown in Fig. 3. In this particular case the four detectors were placed at distances of 300, 400, 500 and 600 feet from the shot along a line through the shot point. One thirty-second of a pound of dynamite was detonated in a twenty foot hole which had been dug about three feet into the water table. The record shows

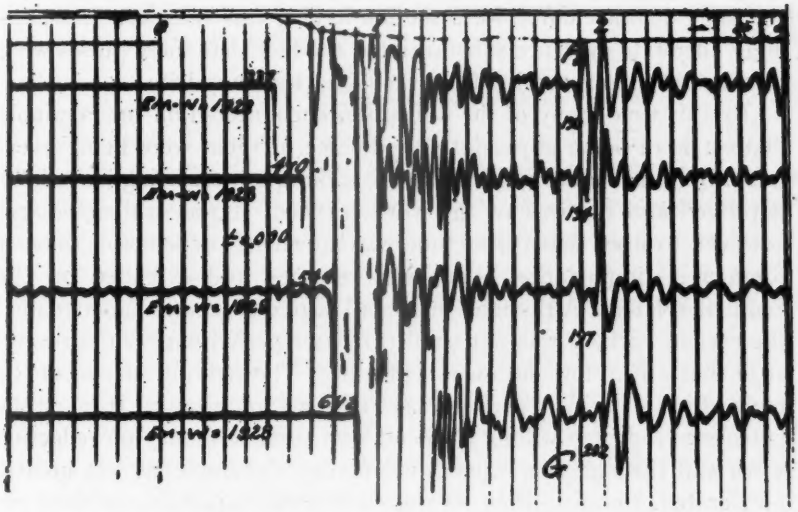

FIG. 3. Reflections from Cimarron Anhydrite, Central Kansas (Shot in 1929).

a high amplitude reflection arriving approximately two-tenths of a second after the instant of detonation of the shot which corresponds to a depth of approximately 730 feet for the reflecting horizon.

It was decided to give the method a thorough checking in this area. First, two core holes a few miles apart were drilled to the Cimarron at locations where the depth was about 500 feet and the relief found in these holes checked with the seismograph. Then in order to prove definitely that these pulses were reflections a detector was placed in one of the core holes directly on the anhydrite and another detector was placed on the surface as far on one side of the core hole as the shot point was on the other side. It was found that the time of travel of the pulse which had been called the Cimarron reflection, to the detector on the surface was almost exactly twice the time of first arrival of the wave to the detector in the hole thereby proving that the energy had

traveled from the surface to the anhydrite and back to the detector at the surface. To clinch the matter finally it was decided to run a long profile. This was done by placing detectors fifty feet apart along a line through the shot point. Reflections were obtained from the vertical out to a distance of fifteen hundred feet from the shot at a location where the anhydrite was approximately one thousand feet deep. The times of arrival of the pulses were plotted against their respective distances and the resulting curve was the same as the theoretical reflection time distance curve for a section having this velocity. Thus, entirely adequate evidence substantiated the fact that these pulses were actually reflections coming from the Cimarron anhydrite.

By this time many of the difficulties encountered on the Seminole Plateau were being appreciated and some of them were being overcome. Both instruments and shooting technique were being materially improved and the cost of the work reduced. It was still necessary, however, to show that the method was sufficiently dependable to be of commercial importance. Work was resumed and extended on the Seminole Plateau. Although some small degree of success had attended the earlier work, it was not until this later period between 1929 and 1932 that a firm foundation was attained. The striking success of the method in this critical period was of extreme importance. It made the petroleum industry willing to spend vast sums of money on reflection work and through this expenditure further development was greatly accelerated. Because, then, of their historical importance several examples of these relatively early reflection discoveries will be given and discussed.

However, prior to a discussion of these areas a short outline of the procedure used in obtaining the seismic data will be given. Four detectors were placed on a line running through the shot point with a distance between each detector of two hundred feet. The distance between the shot and the first detector was approximately a thousand feet. Frequently the spread of detectors was then picked up and moved out along the line so that the first detector of the second spread occupied the same position as the last detector of the first spread. Low places were picked for the shot points and holes were dug into the water table. Usually dynamite charges of only a few pounds sufficed. These charges were detonated electrically and the instant of detonation, the so-called time break, was recorded on the seismogram. This was accomplished by having an electrical circuit broken by the ex-

plosion and the electrical pulse so generated was transmitted to the recorder either by wire or by radio.

Very early in the work it was recognized that there was an irregular layer of low velocity material near the surface which frequently introduced appreciable errors in the times of arrival of the reflections. In order to correct for these weathering variations a series of short refraction shots was taken at each recording spread. From the times of arrival of the refracted energy at the different detectors it was possible to make corrections which helped to compensate for these variations in velocity near the surface.

THE SOUTH EARLSBORO POOL

The South Earlsboro Pool lies in Secs. 22 and 23, T. 9 N., R. 5 E., Seminole County, Oklahoma. At the time of the early Seminole activity a surface nose focused attention on this area. Reflection work in early 1928 indicated a high point in the southeast part of Sec. 23 but because of the questionable nature of the data no action was taken on it. However, the area received a test and in the spring of 1929 a dry hole was drilled in the SE SW SE of Sec. 23 and showed that the high point on the seismic work was due to a miscorrelation. A short time later another well was drilled in the SE SW NE of Sec. 22. These wells are marked 1 and 2 respectively in Fig. 4. Since Well No. 2 was sixty feet higher than Well No. 1 and produced a small amount of oil the possibility of a small structure in the vicinity of Well No. 2 was suggested. Consequently it was considered advisable to reshoot this area, which was done in the fall of 1929, indicating a small anticline in Secs. 22 and 23 with sixty feet of closure. All the wells which had been drilled in this immediate area prior to the time of this shooting are also shown on this map. Subsurface velocities had been determined by lowering a detector in Well No. 1 at the time it was drilled so that the reflections obtained had been definitely tied to proper horizons. Several of the datum figures on the Viola were above −3200 feet, the accepted datum necessary for Wilcox production at that time. This feature added attractiveness to a play which otherwise might have been of only minor interest because of its small closure. It is interesting to compare the amount of shooting in this immediate area, as shown on Fig. 4, with the amount now considered necessary to delineate a structure of this size, as shown later by Fig. 15.

Fig. 5 shows all the wells which have been drilled on this structure.

The contouring is on the top of the Viola with the same contour interval as the geophysical map. Many of the wells were quite crooked, some of them being more than 100 feet lower than wells on either side, consequently only those with crooked hole corrections were used in

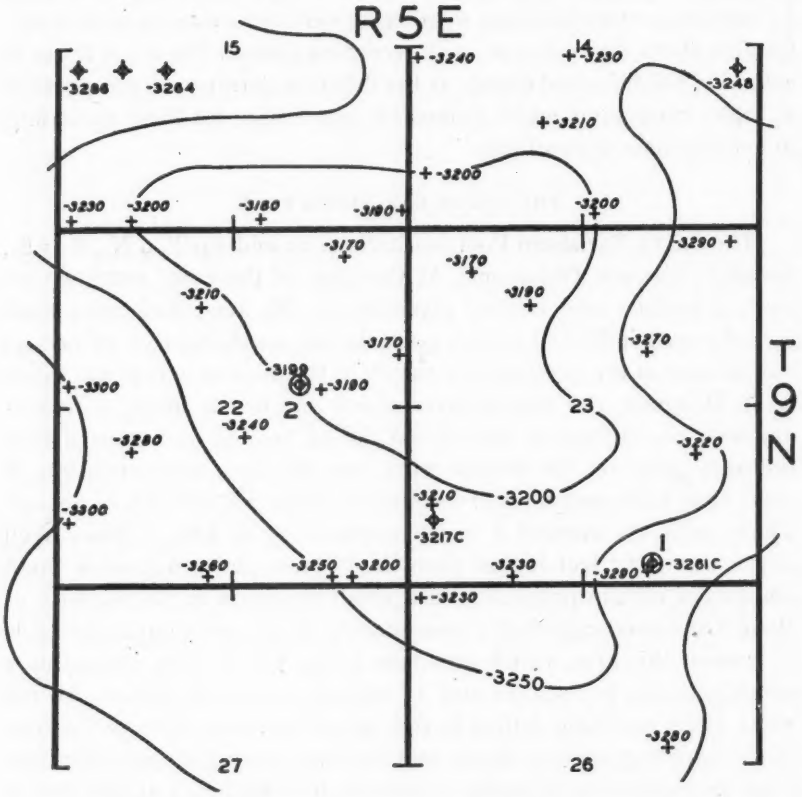

FIG. 4. Seismic Map of South Earlsboro; Viola Lime Structure (Shot in 1929).

the contouring. As is frequently the case with wells in this area several of them behaved in a freakish manner, Well No. 4 was a dry hole and yet it was flat on the Viola with Well No. 5 which was good for several thousand barrels a day.

Examples of records obtained on this prospect are shown in Fig. 6. Judged by present standards they would be considered poor yet there was an unmistakable character to most of them. The times marked "A" on the records were picked as the arrival times in the Viola re-

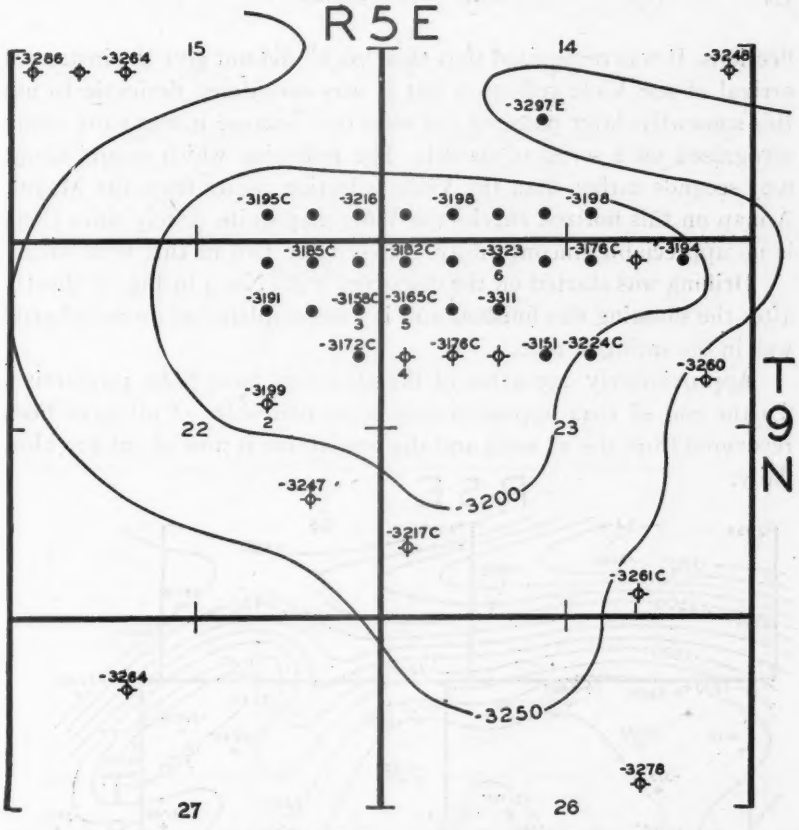

FIG. 5. Production Map of South Earlsboro; Viola Lime Structure. Depths Corrected for Crooked Holes are Marked "C."

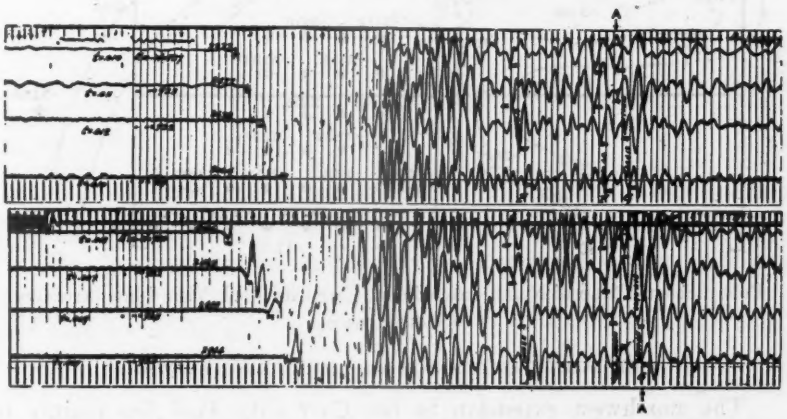

FIG. 6. Typical Seismograms of South Earlsboro Area (Shot in 1929). Viola Reflection Marked "A."

flections. It was recognized that this "pick" did not give the instant of arrival of the Viola reflection but it was considered desirable to use this somewhat later phase of the reflection because it was more easily recognized on a series of records. The reflection which occurs about 0.03 seconds earlier than the Viola reflection comes from the Mayes. A map on this horizon checks the Viola map quite closely since there is no appreciable unconformity between the two in this local area.

Drilling was started on the discovery well (No. 3 in Fig. 5) shortly after the shooting was finished and it was completed as an 8000 barrel well in the spring of 1930.

Approximately 250 acres of the structure have been productive. To the end of 1944 approximately 9,500,000 bbls., of oil have been recovered from the 28 wells and the production is now about 500 bbls. daily.

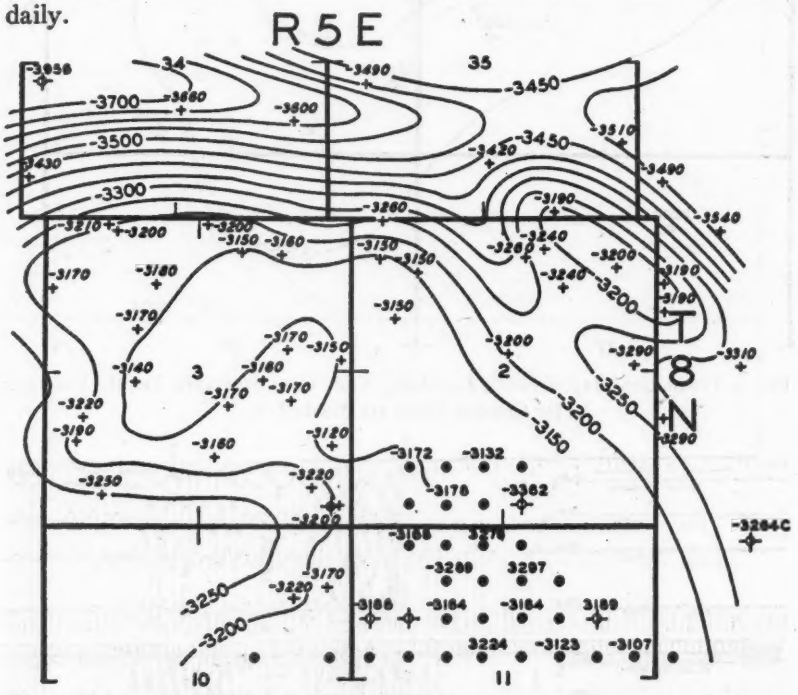

FIG. 7. Seismic Map of North Extension of Carr City Pool; Viola Lime Structure (Shot in 1930).

THE NORTH EXTENSION OF THE CARR CITY POOL

The northwest extension to the Carr City Pool lies mainly in Secs. 2 and 3, T. 8 N., R. 5 E. Due to the fact that the Carr City

Pool had been somewhat of a disappointment it was still open to the north partly, no doubt, due to the low dry hole in the NW SW of Sec. 34 which indicated that the structure dropped off quite rapidly. However, the fact that the field was open on one side contributed strongly to the feeling that the area should be worked and a crew began exploration here in March of 1930. The first position

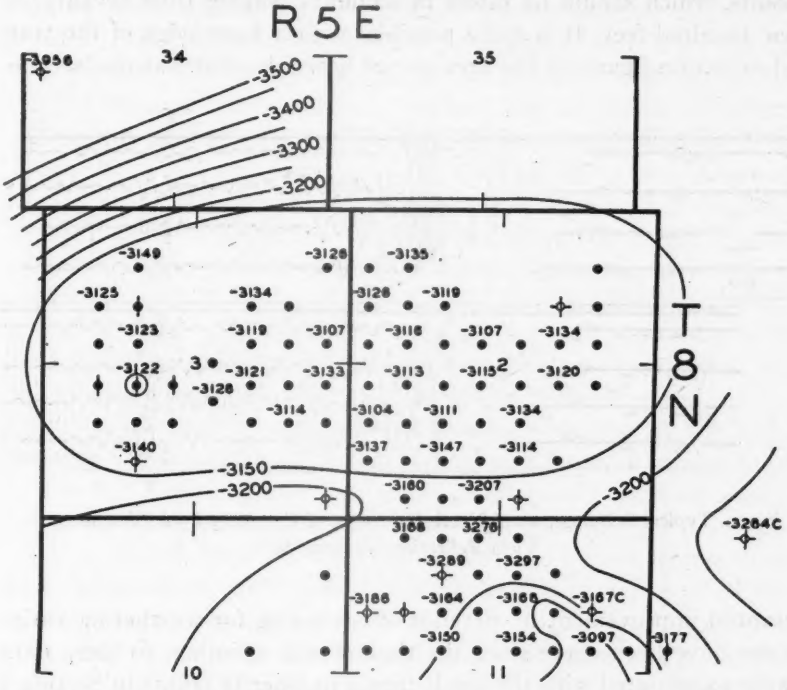

FIG. 8. Production Map of North Extension of Carr City Pool; Viola Lime Structure. Depths Corrected for Crooked Holes are Marked "C." Discovery Well Circled.

taken was over the dry hole in the southeast corner of Sec. 3, which was used as a calibration well for checking the velocity of the section. Fig. 7 shows the geophysical data in this area.

The shooting showed an area around the center of Sec. 3, which was from 50 to 100 feet higher than the wells in the southwest of Sec. 2. There was every reason to expect that this newly discovered high, or extension, would be productive and this expectation was justified when the well in the NW NE SW of Sec. 3, which is circled on Fig. 8, was drilled into the Wilcox sand in the fall of 1930 and came in as a 2700 barrel well, thereby proving the area.

The locations of the wells which have been drilled to date are shown in Fig. 8. The contouring is on the Viola. A comparison between the two maps shows some errors in the geophysical map. The east dip shown across the center of Sec. 2 is not present and the local high in the northeast of Sec. 2 is but a part of the broader high. A miscorrelation of one cycle, or one leg, was made in this group of points, which should be raised in amounts ranging from seventy to one hundred feet. It is quite possible, with a knowledge of the true Viola datum figures in the area, to see how this error was made. Sub-

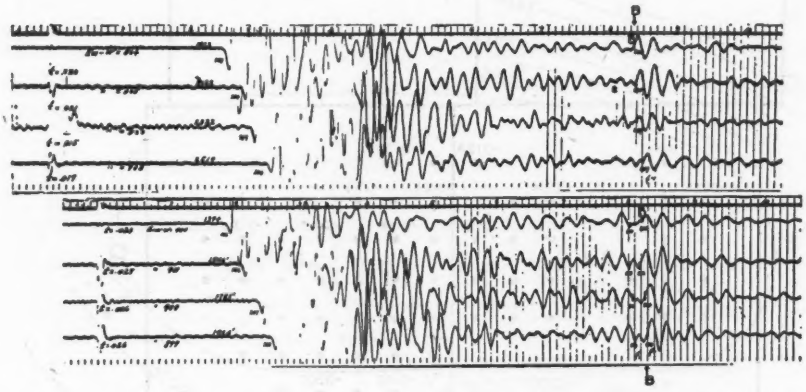

FIG. 9. Typical Seismograms of North Extension of Carr City Pool (Shot in 1930). Viola Reflection Marked "B."

stantial improvement in methods of correcting for weathering variations have been made since the time of this shooting, so these data were recomputed with the result that a number of points in Section 3 were raised twenty to thirty feet, thereby more nearly conforming to the Viola structure shown by the wells.

Examples of records obtained in this area are shown in Fig. 9. These records do not differ materially from those shown in the South Earlsboro area. Since the areas are fairly close together and the geologic section is about the same a similarity in character should be expected. The points marked "B" on the records are the instants of arrival of the Viola reflections.

Approximately 600 acres have produced better than 18,000,000 bbls. from 50 wells and the current daily production is approximately 1100 bbls.

THE WEST SEMINOLE POOL

The West Seminole Pool lies mainly in Sec. 29, T. 9 N., R. 6 E., Seminole Co., Okla. It is immediately southeast of the East Earlsboro Pool and is one and one-half miles west of Seminole City. Attention was originally focused on the area because subsurface control indicated that it was abnormally flat. This led to some very early seismic work of questionable character which suggested that the area might be high. This interpretation, however, was not substantiated by the very low well which was drilled in the northwestern part of Sec. 28 about the time this early work was finished. The last well drilled in the area prior to this shooting was the dry hole in the northeast corner of Sec. 31. This well was higher than the wells around it and had some dead oil in the Wilcox sand, a characteristic of edge wells in the East Earlsboro field. Although Sec. 29 had several dry holes around it, some of them quite low, it was not impossible for this area to contain a small structure. This immediate area was carefully shot in the fall of 1929 and the early spring of 1930. The locations of the dry holes which had been drilled prior to this later shooting are shown in Fig. 10. The well near the N.E. corner Sec. 30 was shot over first and the velocity was adjusted to make the outstanding reflection fit the Viola datum in the well. This velocity was employed for calculating all the data in this area. The locations of the geophysical points are shown in Fig. 10, which shows an anticline with one hundred feet of closure which is cut off from the East Earlsboro pool by a syncline. Ten scattered positions, which gave no reflections, have been left off the map for the sake of clarity.

In August, 1930, the first test well which is circled in Fig. 11 was drilled in the NW NE SW of Sec. 39 and completed as a 3000 barrel well in the Wilcox sand. Shortly before this well reached the Viola it caused a mild panic. On the top of the Brown lime, which is several hundred feet above the Mayes, it was 170 feet lower than the low well near the northwest corner of Sec. 28. From this point on the section thinned and the well had a Viola datum of -3125 feet, making it 365 feet higher than this well and 127 feet higher than the well near the northeast corner of Sec. 31.

Fig. 11 is a contour map on the Viola lime. With the exception of the points on the extreme eastern edge of the map, the geophysical map is checked quite well. Most of the geophysical figures are within twenty feet of the well values, making allowance for the ten foot dif-

ference at the calibration well in the northeast corner of Sec. 30. There are, however, two or three cases where the difference is as great as forty feet. Every effort was made to find the cause of these discrepancies. The correlations on the whole appeared sound. It could have been assumed that there were local variations in velocity suf-

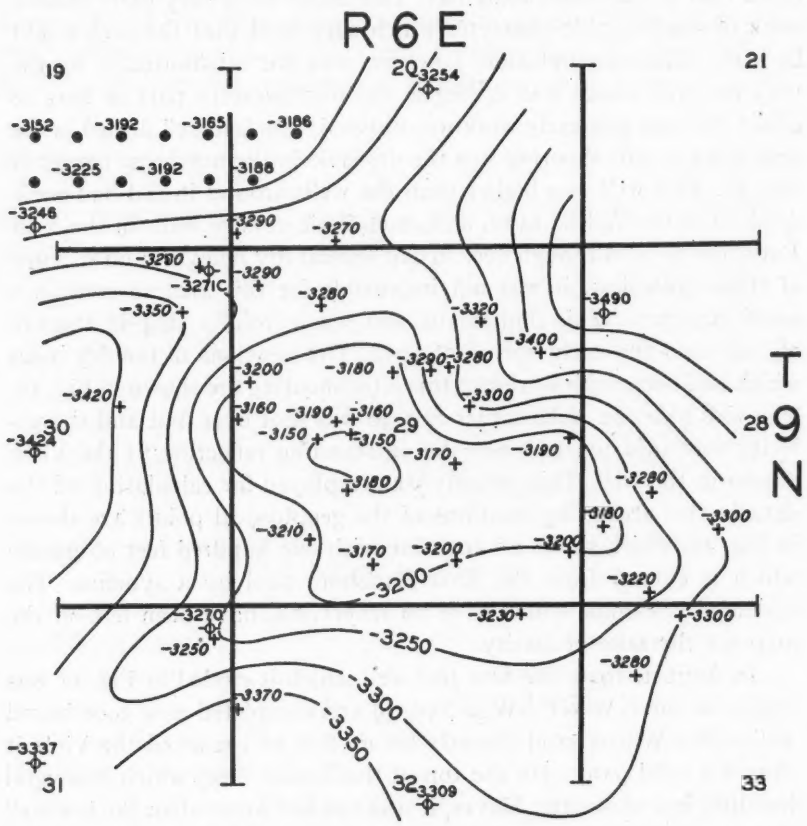

FIG. 10. Seismic Map of West Seminole; Viola Lime Structure (Shot in 1929–30).

ficient to account for these differences but experience showed this was unlikely. When a newer method of correcting for weathering was used most of these irregularities disappeared.

The paucity of data in the southeast quarter of Sec. 30 should be noted. A few years ago this immediate area was shot very carefully,

resulting in the discovery of another small Wilcox pool in the south half of this section.

Examples of the records obtained in this area in 1930 are shown in Fig. 12 on which the instants of arrival of the Viola reflections are

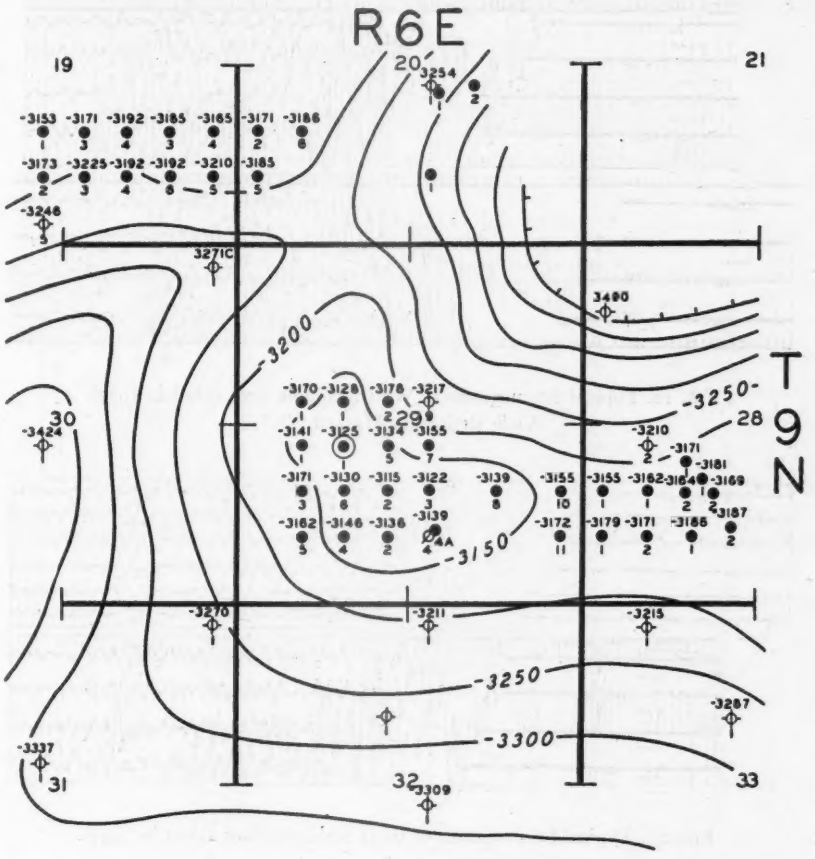

FIG. 11. Production Map of West Seminole; Viola Lime Contours.

marked "B." The character of the Viola reflection made it quite recognizable and correlatable in most instances. The only records where a mistake in correlation was made were those in the eastern part of the area where Viola figures of about −3300 are shown. With the added experience since this correlation was made it is easy to show

that the instant of arrival of the Viola reflection was picked too late in these cases and that, instead of the values shown, they should be about −3200. These records had fair reflections on them but the

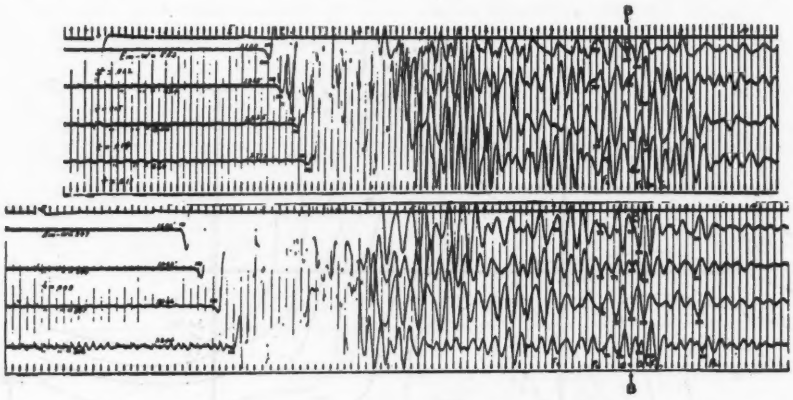

FIG. 12. Typical Seismograms of West Seminole Area (Shot in 1930). Viola Reflection Marked "B."

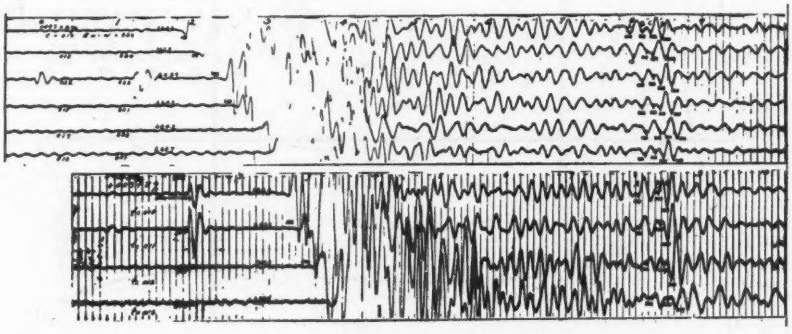

FIG. 13. Typical Seismograms of West Seminole Area (Shot in 1932).

character was not quite the same as shown on the records in Fig. 12, consequently there was a choice as to which points on the reflection should be picked and, unfortunately, the wrong ones were chosen.

Another reflection group was frequently obtained a few hundredths of a second ahead of the one from the Viola. This was not as consistent in either amplitude or character as the Viola reflection. Generally it was a doublet coming from the Mayes and Woodford.

In the spring of 1932, a few additional positions were added to as-

sist in making well locations. At the same time the data which had been previously shot were reevaluated with the result that some very minor changes were made.

Records of the 1932 shooting are shown in Fig. 13. They demonstrate rather conclusively the marked improvement in record quality

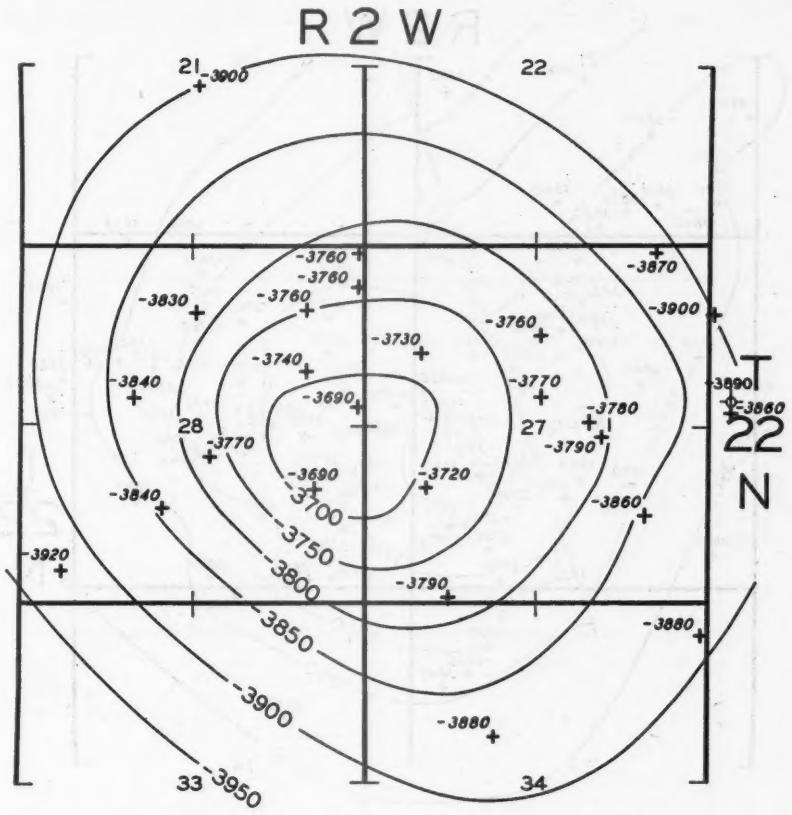

FIG. 14. Reconnaissance Seismic Map, Polo Area, Oklahoma.
Viola Lime Structure (Shot in 1931).

during these two years. It will be noticed that one of these records has six traces. The change to this type of record was made during this program.

Out of 35 wells drilled, on approximately 500 acres, the production to the end of 1944 was nearly 15,000,000 bbls. with a daily production of better than 900 bbls.

The above three examples will serve as an illustration of what was being done in 1930 with the seismic reflection method. No apologies need be made for the quality of that work. However, it should be borne in mind that great improvement has been made since that time and it would be unfair to judge this early work too critically. In order to

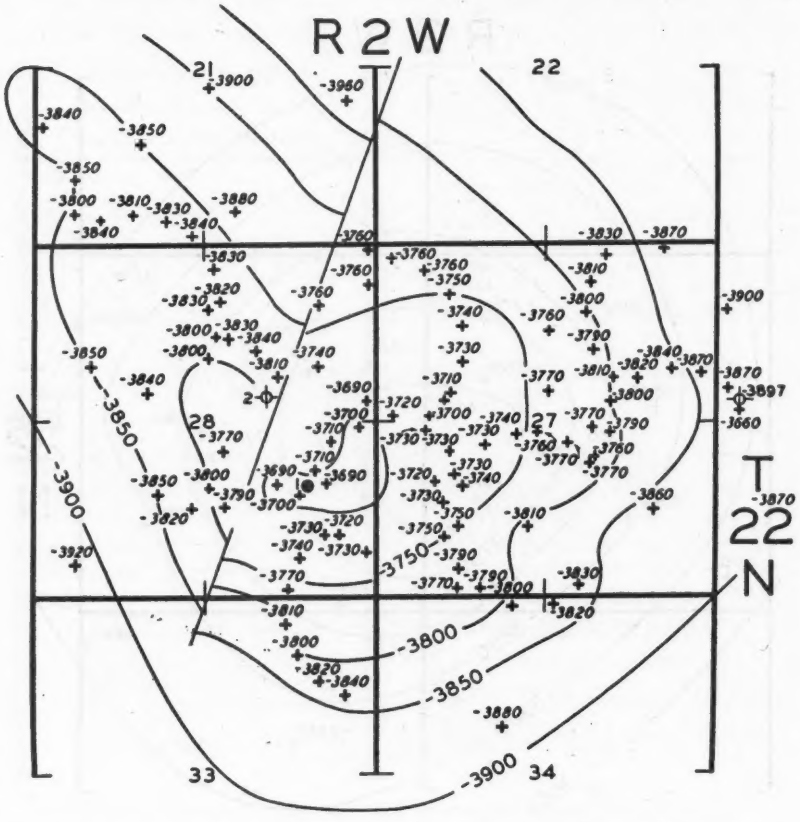

FIG. 15. Detailed Seismic Map, Polo Area, Oklahoma. Viola Lime Structure (Shot in 1934).

show the rapid progress in the art at that time a short description of the shooting and discovery of the Polo field will be given.

POLO

This field, which lies in Secs. 27 and 28, T. 22 N., R. 2 W., Noble County, Okla., was one of the fields found as a result of a reconnais-

sance survey of several counties in central Oklahoma. The customary procedure in this regional program was to have a datum point on each section corner. If one of these points gave an abnormal value other positions were added around it and an approximate outline of the structure obtained. After leasing, the anticline was usually shot in some detail in order to pick the highest point for a well location.

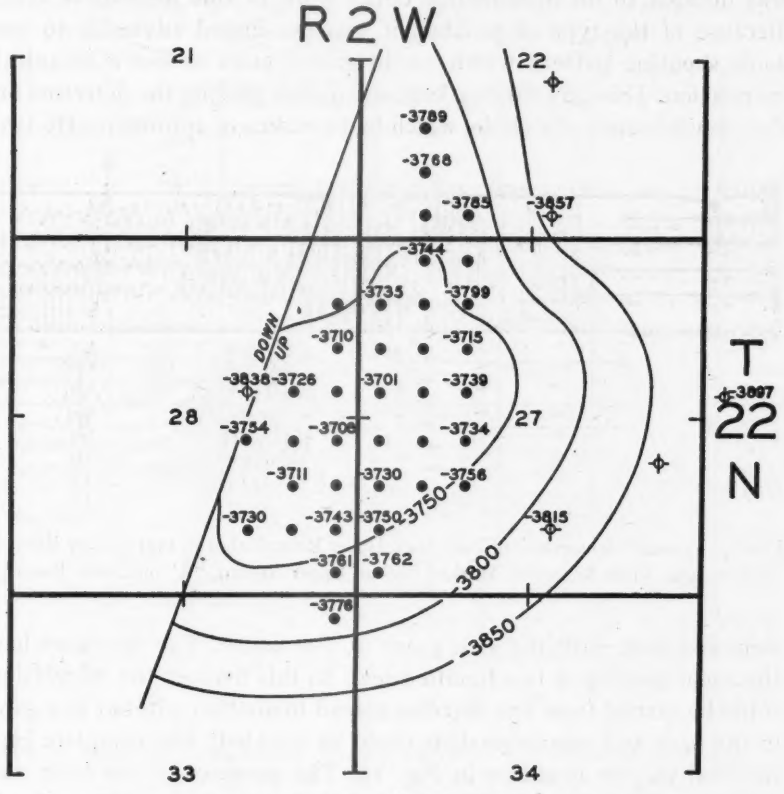

FIG. 16. Production Map of Polo Field; Viola Lime Structure.

The regional survey was extended into this township in July of 1931 and the anomaly was indicated immediately. A sufficient number of points was added to delineate the structure roughly. The structural picture is shown in Fig. 14.

A dry hole, drilled in 1926 in the SW NW Sec. 26, indicated that the reflections were from the Viola. Velocity control had been obtained previously from wells some little distance away.

The discovery well was completed in April, 1934 as a good well in the Wilcox sand. This is well No. 1 on Fig. 15. The second well which was completed in July of 1934 was on the down throw side of a small fault and was a dry hole. It is shown as well No. 2 in Fig. 15. In order to evaluate the leasehold, to find the direction of the fault, and possibly to save the drilling of a dry hole on the edge of the structure it was decided to do considerable detail work in this immediate area. Because of the type of problem it was considered advisable to use some shooting pattern which would give a more or less mechanical correlation. This was done in August, 1934 by placing the detectors on the circumference of a circle, which had a radius of approximately two

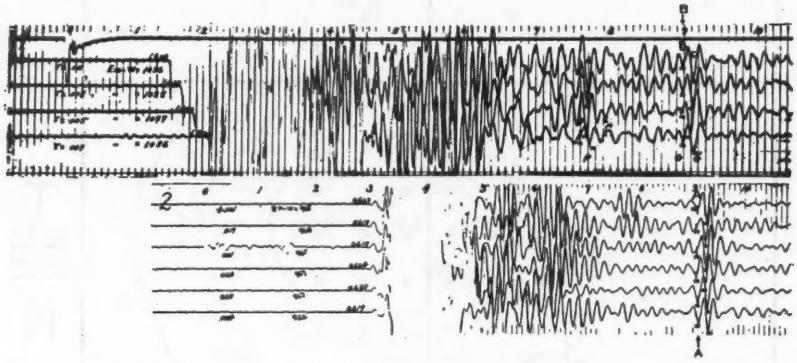

FIG. 17. Typical Seismograms of Polo Area. Upper Record, shot in 1931; Lower Record, shot in 1934. Viola Reflection Marked "B" on Upper Record, "A" on Lower Record.

thousand feet, with the shot point at the center. The detectors had the usual spacing of two hundred feet. In this manner the correlation could be carried from one detector spread to another without any gaps in the data and miscorrelations could be avoided. The complete geophysical picture is shown in Fig. 15. The presence of the fault was verified and an accurate picture of the whole structure was determined. Fig. 16 shows the wells in this area contoured on top of the Viola. A comparisons of Figs. 15 and 16 will show that there is remarkably little variation between the geophysical and well values on the top of the Viola.

Fig. 17 shows two of the records obtained in this area. Record No. 1 is an example of the 1931 shooting and Record No. 2 of the 1934 shooting.

The points marked "B" on the 1931 record and the points marked "A" on the 1934 record represent the phase of the Viola reflection which was used. The first breaks or first arrivals of the refracted energy clearly indicate the difference in the two methods of shooting.

To the end of 1944 the field had produced approximately 4,500,000

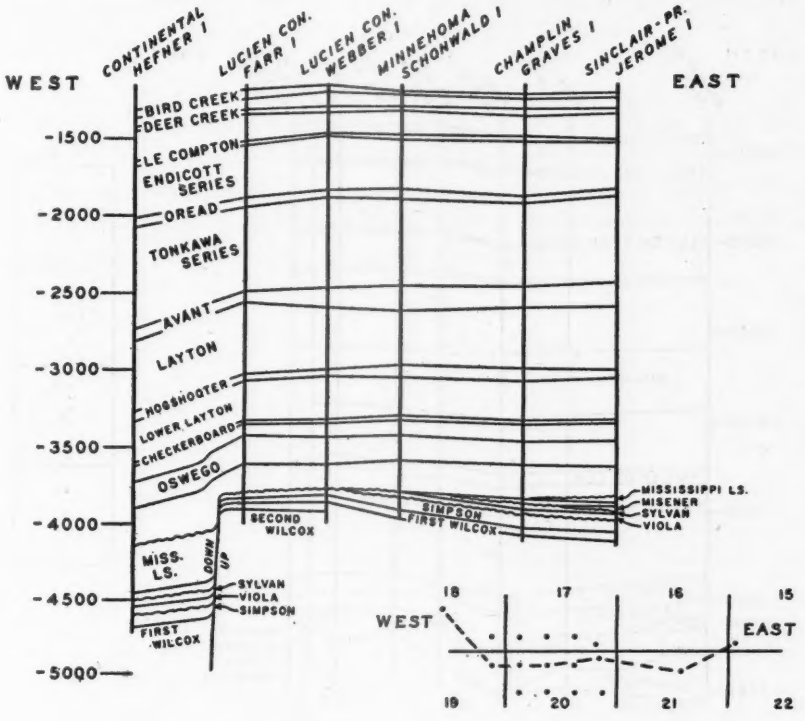

FIG. 18. West-East Cross Section Across Lucien Pool, Noble County, Oklahoma.

barrels from 37 wells and was producing at an approximate daily rate of 500 bbls.

After shooting had spread from the Seminole Plateau to other parts of Oklahoma such geological anomalies as are shown in Figs. 18 and 19 were encountered occasionally. Such conditions, involving truncation, are difficult to predict with the seismograph and involve much tedious work. In spite of such occasional difficulties vast areas

have been mapped where the work has been of good quality, where the reflections have been tied to the correct beds (obtaining velocities by lowering a detector in a well has helped a lot in this respect) and where structures have been mapped with commendable accuracy using very good quality reflections.

Since the time of this early work many and varied improvements

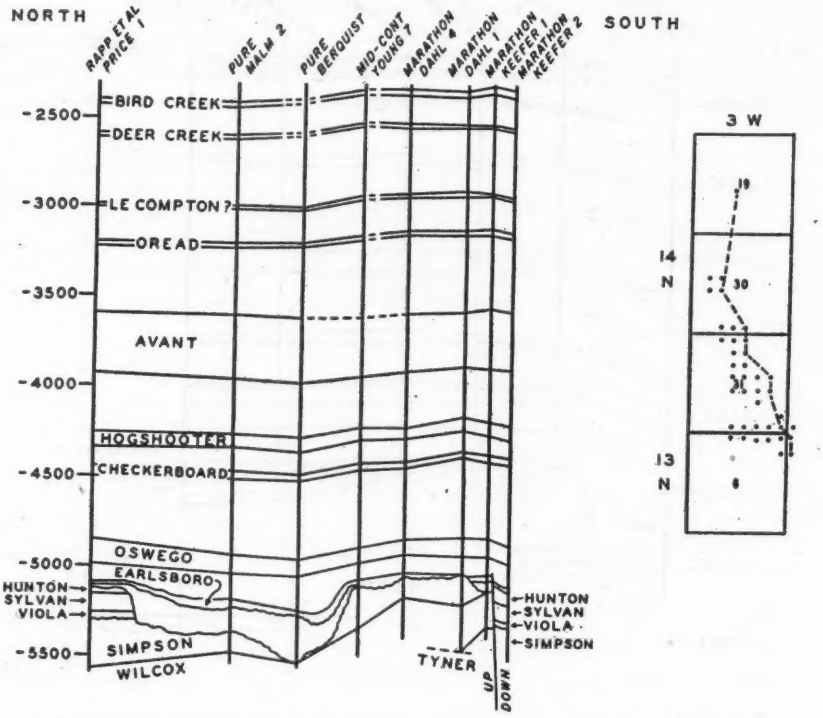

FIG. 19. North-South Cross Section Across Edmond Pool, Oklahoma County, Oklahoma.

have been made in both instruments and technique. It is the exception now to find an area where the reflection method cannot be applied satisfactorily. Problems unworkable a few years ago have yielded to very dense shooting and to continuous profiling. The seismograph has even been used in an effort to work out the details of certain types of stratigraphic traps such as wedges and pinch outs. While the current high level of activity is primarily due to the unprecedented requirements for petroleum there is no need to adopt a pessimistic attitude

toward the future of seismic prospecting as long as improving techniques help us to cope with the complexities of nature and as long as there are vast areas in the United States that have never been explored geophysically because they are as yet beyond the petroliferous frontiers. Some of the problems being tackled are too advanced for the present state of the art and attempts to find unique solutions to them will undoubtedly lead to errors in interpretation. However, it is through just such efforts that progress will be made.

ACKNOWLEDGMENT

Parts of the data contained in the above report are the joint property of the Stanolind Oil and Gas Company and the Amerada Petroleum Corporation, the remainder are the sole property of the Amerada Petroleum Corporation. The writer is deeply indebted to both companies for their release of this material.

THE MAGNETIC FIELD OVER IGNEOUS PIPES

VICTOR J. BLUM, S.J.

ABSTRACT

In this paper a brief summary of a magnetic survey of the Canon City, Colorado, area is presented. The primary object of the article is to give the results of magnetic traverses over exposed igneous pipes which contain an appreciable amount of magnetite. These traverses reveal a magnetic low near the geometric center of the tops of the pipes. Away from the center the field increases in intensity and reaches its maximum strength along the southern edge of the intrusion. Small igneous pipes at or near the surface cause radical changes in the magnetic field within very short distances.

The purpose of this paper is to present some isolated features of a magnetic survey conducted in the Canon City, Colorado, area in the spring and summer of 1943. These features are of interest because they deal with the magnetic field in sedimentary horizons pierced by igneous pipes. Since a full report on the results of the magnetic survey in the Canon City area has been published[1], only a summary of the survey will be given here. To better appreciate the results of the survey a glance at the geology will be helpful.

The region under discussion is in the Canon City embayment formed by the en échelon pattern produced by the Rocky Mountains of the Front Range and the Wet Mountains. The region, which is named after the town of Canon City lying near the center of the area, is about eleven miles long and eight miles wide. As can be seen in Fig. 1 rocks ranging from Pre-Cambrian to Tertiary deposits may be found in this rectangular section. About one-half of the area is occupied by the granites, gneisses and schists of the Pre-Cambrian, and these constitute the mountainous parts of the region. The Paleozoic, Mesozoic, and Cenozoic limestones, shales, and sandstones occupy the remaining flatter portion. These sediments lie in a syncline which enters our area at the north and pitches to the southeast. In general the western limb of the syncline rests at a fairly steep angle on the Pre-Cambrian. The eastern limb leans on the Pre-Cambrian barrier of the Front Range which here pitches southeastward under the sediments.

With this rapid view of the geology of the area as a background we may now observe some of the results of the magnetic survey, but before doing so a word about the instrument used and the type of survey

[1] Am. Geophys. Union; Trans. 1944, Part IV, pp. 556–558.

conducted is in place. The Askania Schmidt magnetic balance was employed. The investigation was restricted to the vertical component. Since magnetic fields of great variations were found, besides an ordinary auxiliary magnet a very strong one on a long calibrated track was constructed and used in observing intense and very weak fields.

An examination of the northeastern section of the Magnetic and Geologic Map (Fig. 1) suggests a correlation of the synclinal structure with the distribution of the magnetic field. The nearer the basement complex is to the surface, the more intense is the field. Other interesting correlations are the magnetic highs with the pegmatitic dikes in the northwestern corner of the map. Noteworthy, also, is the manner in which the magnetic contours practically parallel the elevation contours around Fremont Peak (at FP in Fig. 1) and the ridge leading to it from the north-northwest. One of the most enlightening correlations is the great, narrow magnetic low in the south-central region of the map. At the west end of this low there is a vertical fault between the Pre-Cambrian and the sedimentary rocks. Geological field evidence for the continuation of this fault to the east is obscured by piedmont deposits. However, on the basis of the existence of the magnetic low along the base of the mountains, we seem to be justified in making the fault coextensive with the low.

Since our purpose is to examine certain detailed features of our magnetic survey, the above summary of the general outlines of the survey will suffice. The matters to be discussed here are not indicated on the Geologic and Magnetic Map as the areal space occupied by them is too small to be shown.

Two and a half miles south of Canon City there are three known places of igneous intrusions into the sedimentary rocks. Two of the intrusions are preserved in steep hills which remind one of small volcanic cones. One of them (at A in Fig. 1) is about two and a half miles south-southwest of Canon City just to the left of the road leading out to the Indian Burial Ground Monument. The second hill (at B in Fig. 1) is about one mile east-southeast of the first hill. The third intrusion is a thousand feet northeast of the second hill, and forms a low mound several feet high. These two hills and the mound in which are preserved the igneous pipes are the result of differential erosion. Except for the igneous material forming the core, the hills consist of the same rock material as that of the immediately surrounding geological horizon, namely, shale.

The intrusive rock in question is of a gray-black dense type. Ex-

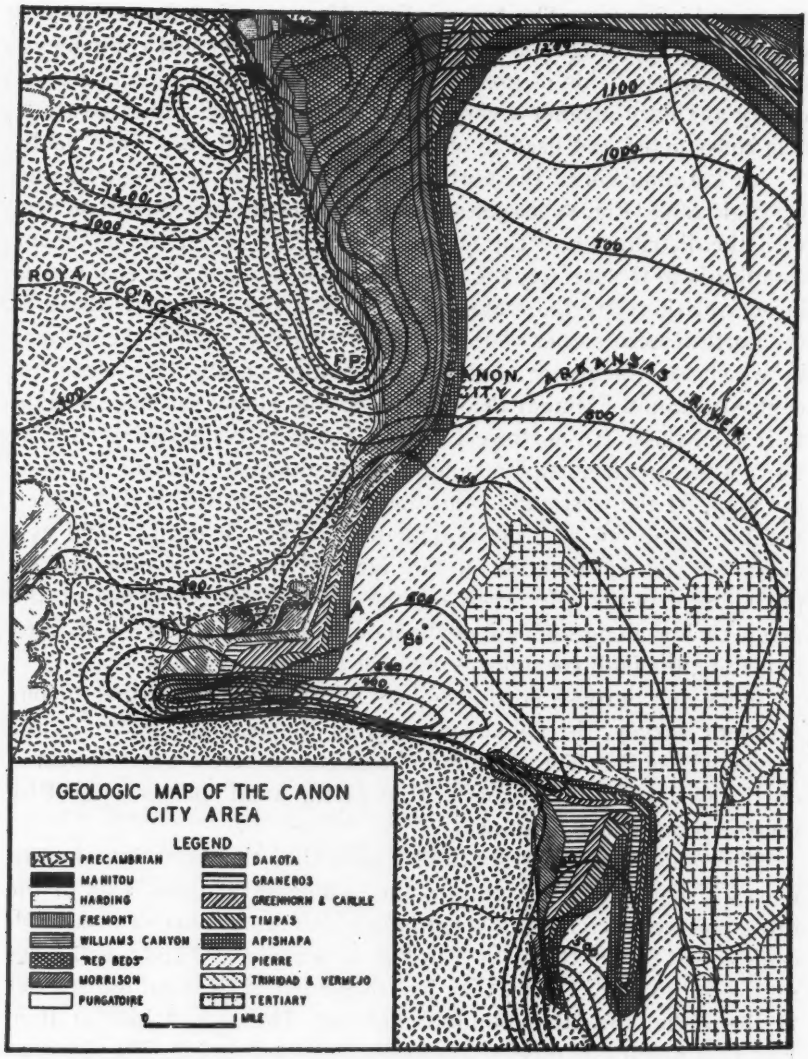

FIG. 1. Vertical component magnetic contour lines placed on the Geologic Map of the Canon City area. The contour interval is 100 gammas.

cept for a few large crystals it is fine-grained and homogeneous in its appearance. A thin section of the rock presents under the petrographic microscope a maze of small crystal-lathes of feldspar, ferromagnesian material interspersed with particles of magnetite. Some sections reveal

pronounced flow structure not visible in a hand specimen. Crystals of magnetite are arranged along curved lines which are separated from one another by parallel lathes of feldspar and ferromagnesian crystals. For the most part the magnetite particle is 0.025 millimeter long in its longest dimension; some few are 0.1 millimeter long. On an average the number of particles per square millimeter ranges from 300 to 700.

With some knowledge of the igneous rock over which our magnetic observations were made, let us turn our attention to the place referred to above as the first hill. This cone-shaped mass of sedimentary and igneous rock is over a hundred feet high. It is difficult to determine the outline or extent of any one of the many igneous pipes which are partly exposed and partly hidden under talus and vegetation. The top of the hill consists of a crescent-shaped, fairly flat ridge, one end of which points toward the east, the other northwest.

On this ridge a number of magnetic observations were made. The horizontal distribution of the points of observation is shown by Fig. 2. Most of the readings were made over the southern edges of partial outcrops of pipes, while a few were taken in grassy places whose position relative to the intrusions was unknown. The results of these observations are shown in the same Fig. 2. The readings whose values were above normal of the surrounding place are shown as positive and those which were below this normal are shown as negative. One obvious conclusion to be drawn from this set of readings is that, although the hill on which they were made is highly restricted in area, no one reading can be said to be representative of the place. It is true, however, that the amplitude of the highs is greater than that of the lows. Another conclusion to be drawn is that not only is any particular reading not representative of the top of the hill, but a particular reading can be predicated only of the actual spot where it was observed. By moving the magnetometer a few feet an entirely different intensity can be encountered. Such behavior is not found in sedimentary horizons. Nor are igneous horizons as such to be considered highly erratic in the distribution of the magnetic field over them. Large tracts of granite south of the Royal Gorge of the Arkansas River manifested a quite uniformly varying magnetic field. On the other hand, certain igneous regions north of the Royal Gorge were very changeable because of intrusions of different magnetic properties into the original homogeneous granite.

The next part of this paper describes a systematic survey made

over two igneous pipes, whose outlines were symmetrical and exactly known. These two pipes are located in the place referred to above as the second hill (B in Fig. 1). Fig. 3 is a picture of the hill under discussion. The view is to the west. This picture shows a metal tank in the saddle separating two igneous masses, one to the north and the other to the south. The intrusive bodies are vertical cylinders. While the

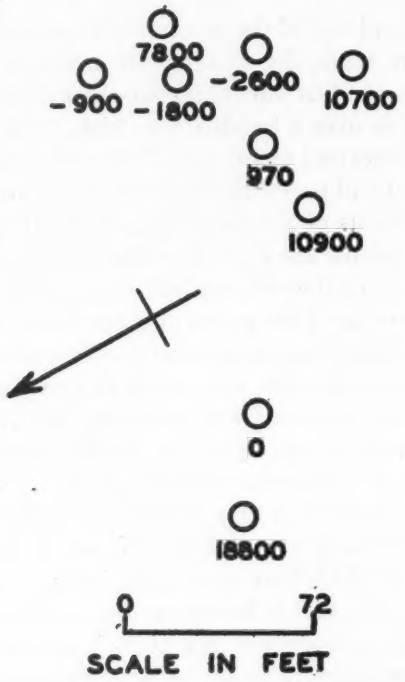

FIG. 2. The horizontal distribution of the points of magnetic observations with their anomaly-values in gammas.

northern body is elongate in cross-section, the other one is quite round and is about 40 feet in diameter.

Magnetic observations were made beginning at the northern base of the double hill, continuing over the top and ending at the southern base. The path followed across the top was such as to pass over the centers of the igneous bodies. The distribution of observation-points can be seen in Fig. 4.

Fig. 4 gives us the results of the investigation. The lines dropping down from the circles indicate the place at which an observation

FIG. 3. Looking west at the hill with two igneous cores.

was made on the hill or igneous pipe. The center of the circle gives the value in gammas of the particular reading. The line drawn across the top of the figure is the zero line, and stands for the average magnetic reading in the immediate vicinity of the hill. Hence, the centers of circles above or below this line give the variation of the vertical

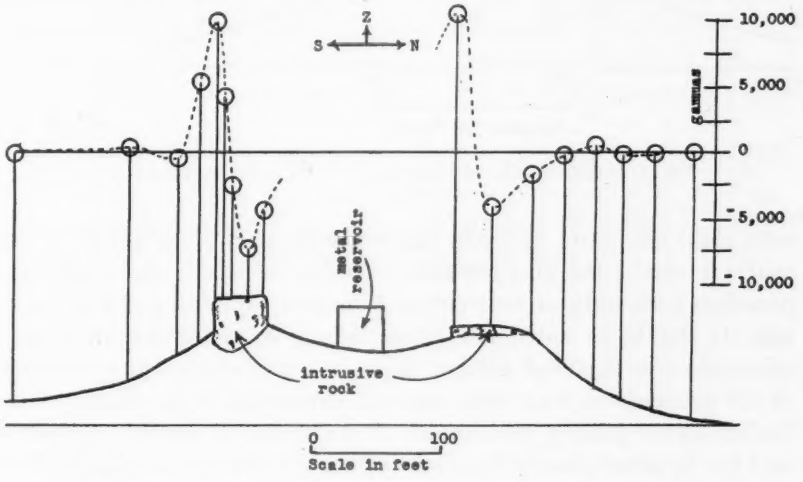

FIG. 4. Magnetic north-south traverse over the two igneous pipes.

magnetic component from the normal field of the surrounding region. The scale at the right indicates the magnitude in gammas of this variation.

The results are interesting. Both igneous exposures show that the magnetic field is weak at the northern end of the pipe. As one moves from the north toward the center of the igneous body the field becomes very much weaker, dropping in the case of the southern pipe to

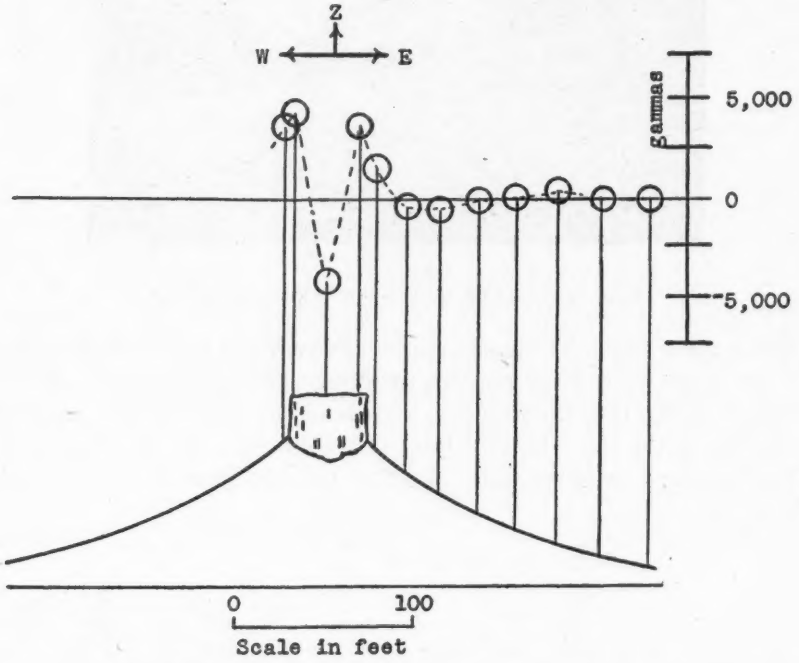

FIG. 5. Magnetic east-west traverse over the south igneous pipe.

over eight thousand gammas below the normal. Continuing to the southern end of the pipe the field-intensity increases, and finally approaches a strength of over eleven thousand gammas above the normal. It should be noted that these values given for maximum and minimum are observed values; they do not preclude the possibility of the existence of even more extreme variations in the vicinity. The broken curve joining the centers of the circles is merely suggestive and has no other observed values to control it than those indicated by the circles. The feature to observe in the results of the north-south

magnetic traverse across these two igneous pipes is the position of the magnetic high and low relative to the igneous body.

In addition to the north-south survey an east-west line of observations was made across the south pipe. This is shown in Fig. 5. The survey began several hundred feet east of the igneous outcrop cutting across its center and ending a short distance west of it. Bearing in mind that the survey passes along the east-west diameter of the igneous pipe shown in Fig. 5, our attention is attracted to the fact that the magnetic field increases in intensity away from the center. When this picture of the magnetic distribution is fitted in with the north-south distribution on the same exposure, we find that the field is more intense along the circular edge of the exposure than toward the central portions, and that the southern half of the circumference has a stronger field than the northern half. That the magnetic high should occur at the southern edge of the igneous pipe can be attributed to the inclination of the earth's magnetic field.

In conclusion we can say that, although a more intensive investigation of this matter is in order, a magnetic high does not seem to occur over the geometric center of small vertical magnetic bodies, but rather it is shifted to the side nearest to the earth's incoming magnetizing field. Also, it would seem possible to outline the position of shallow buried vertical pipes by means of the ring pattern. This pattern, as we saw above, consists of a magnetic field which relative to a magnetically low center is high around the edge of the igneous body. Thus, if a very closely spaced network of magnetic observations were carried out on the first hill which we investigated, it is likely that a clear picture of the number and position of the hidden igneous pipes would result.

Finally, I wish to express my sincere gratitude to the Reverends James B. Macelwane, S.J., and Joseph R. Goberna, S.J., who rendered valuable assistance throughout the entire time that the magnetic survey was conducted in the Canon City area.

GRAVITY AND MAGNETIC INVESTIGATIONS AT THE GRAND SALINE SALT DOME, VAN ZANDT CO., TEXAS*

JACK W. PETERS† AND ALBERT F. DUGAN†

ABSTRACT

During May, 1944, detailed gravity and magnetic surveys were made at the Grand Saline Salt Dome to secure additional information on the physical properties of this typical East Texas salt dome. The results of the surface gravity and magnetic surveys, and the subsurface gravity survey in the Morton Salt Mine are illustrated and discussed.

Densities and the available subsurface data were compiled and were utilized in a quantitative evaluation of the observed gravity data. The theoretical mass distribution which was determined by this quantitative evaluation is not intended to represent the unique solution of the geophysical and geological data; instead, it is offered as a possible solution based on relatively simple assumptions.

INTRODUCTION

In order to secure additional information on the physical properties of a typical East Texas salt dome, detailed gravity and magnetic surveys were made at the Grand Saline Salt Dome. This dome was believed to be particularly adaptable to such investigations because, in addition to surface gravity and magnetic observations, underground gravity observations could be made in the workings of the Morton Salt Company's mine.

The available physical information collected at this dome is presented along with a discussion and interpretation of the geophysical data.

GENERAL DESCRIPTION OF THE GRAND SALINE SALT DOME

LOCATION

The Grand Saline Salt Dome is located in northeastern Van Zandt County, Texas. The town of Grand Saline is situated on the northern flank of this dome. The approximate 60 square mile area covered by the geophysical surveys is outlined in the central portion of the index map in Fig. 1. Three important oil fields and the principal cities and towns in the adjacent area also are indicated on this map.

* Read at the Tulsa, Houston and Dallas meetings of the Society, 1945.

† Magnolia Petroleum Company, Dallas, Texas.

TOPOGRAPHY

A topographic map, contoured at 20 foot intervals and based on elevation control obtained from the gravity survey, is shown in Fig. 2. For correlation purposes, the position of the upper salt mass is indicated by the stippled area. A central depression, containing a salt

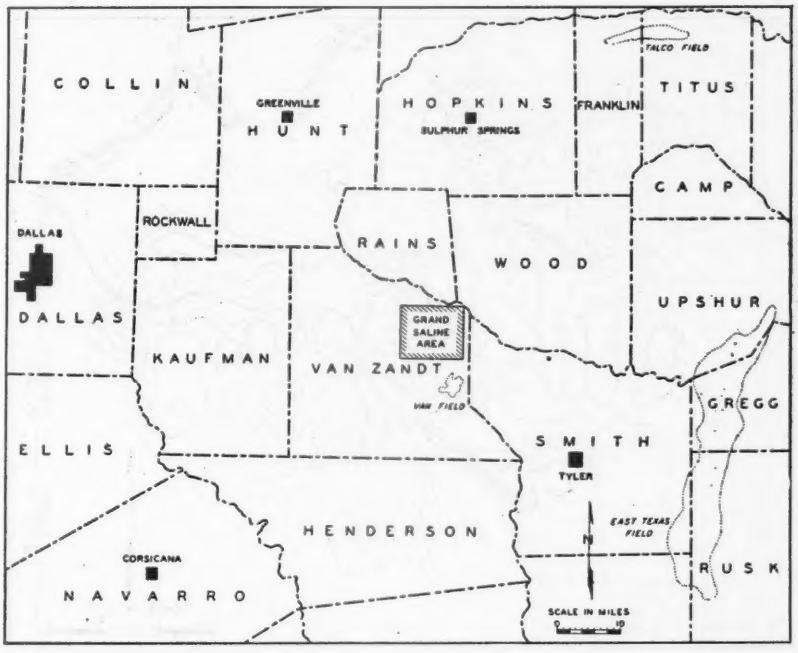

FIG. 1. Index map of Northeast Texas showing location and extent of area covered by geophysical surveys at the Grand Saline Salt Dome. Dotted lines outline major producing areas.

marsh, is situated approximately over the salt mass. Hills, having a relief up to 130 feet, roughly surround the depression.

SURFACE GEOLOGY

According to previously published data, the dome is within the outcrop belt of the Wilcox formation, about three miles west of the Wilcox-Recklaw contact. Steep dips are reported around the dome, but no beds older than Wilcox appear at the surface.

SUBSURFACE GEOLOGY

Several wells have been drilled on the flanks of this dome, but it is understood that none of these wells penetrated formations below the Woodbine. In Fig. 3, subsurface data at the top of the Pecan Gap are contoured at 100 foot intervals.

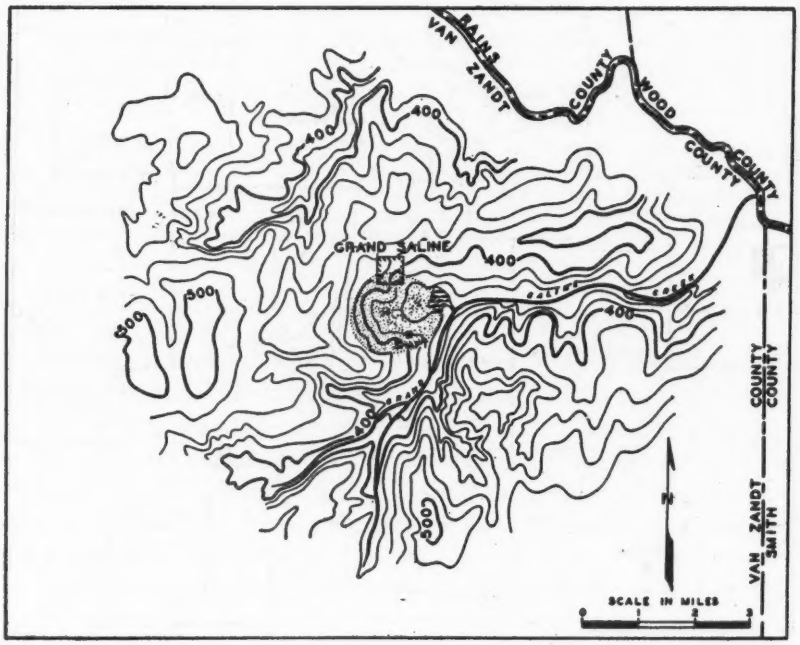

FIG. 2. Topographic map of the Grand Saline Area. The stippled area represents the position of the upper salt mass. Contour interval is 20 feet.

SALT MASS AND CAP ROCK

Numerous shallow salt wells have been drilled into the cap rock and salt. The locations of the wells on, and immediately near the salt mass, are shown in Fig. 4, The available data from the wells located in Fig. 4 are given in Table I. Some of these wells were drilled as early as 1888, and therefore the locations and driller's logs obtained from various sources are questionable and incomplete. According to the subsurface data on these wells, the top of the salt mass, which is outlined by a dashed line in Fig. 4, is roughly circular in shape and has a radius of approximately 4000 feet. Salt has been encountered at depths

ranging from 212 feet to 668 feet, averaging 286 feet. An average salt depth of 236 feet was obtained by neglecting a few of the greater salt depths which are from wells situated near the rim of the dome. The overlying cap material consists of anhydrite, selenite, gypsum, limestone, and calcite. The thickness of this material varies from 5 feet to 61 feet, averaging 28 feet. An average thickness of 30 feet was ob-

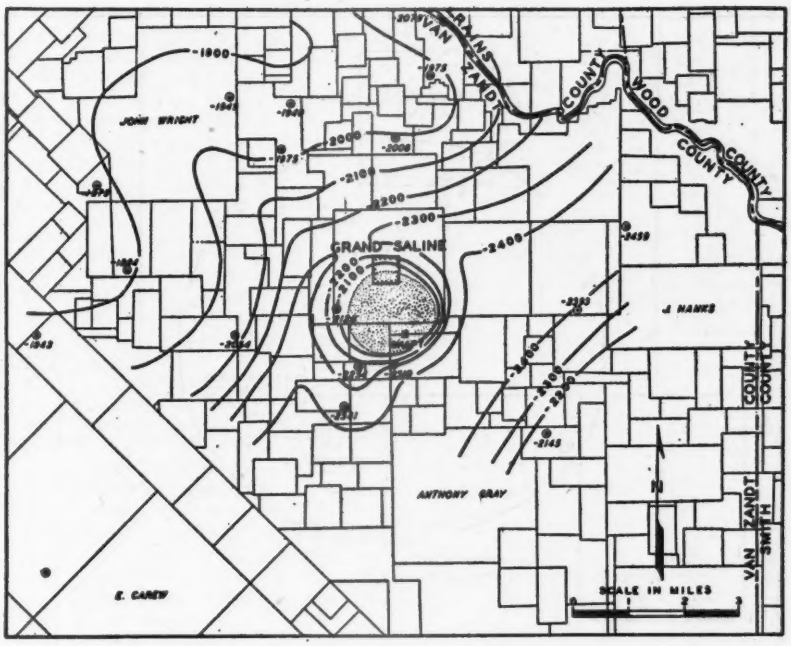

FIG. 3. Subsea contours on top of Pecan Gap. Subsea datum on top of Pecan Gap is shown at well location (double circles). The stippled area represents the position of the upper salt mass. Contour interval is 100 feet.

tained by neglecting the data from wells located on the shoulder of the dome. The underground workings of the Morton Salt Company's mine, located in the southeastern portion of the dome, are also shown in Fig. 4.

PHYSICAL PROPERTIES OF ROCKS FROM THE GRAND SALINE AREA

DENSITIES

Density determinations were made on samples of surface sediments, cap material, fresh-mined salt, and cores of deeper sediments. The re-

sults are tabulated in Table II. The densities of 6 samples of clear salt averaged 2.15 g./c.c. The densities of 2 samples of dark salt, probably containing large amounts of anhydrite, averaged 2.24 g./c.c. Only a very small quantity of this dark salt was apparent in the mine workings. Weathered samples of cap material were obtained from the mine dump as fresh samples were not available. These densities averaged

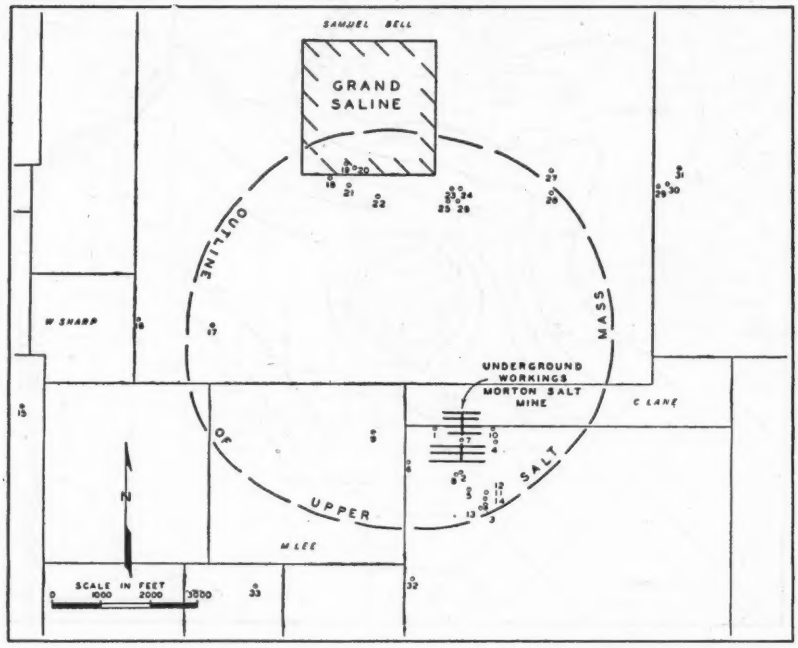

FIG. 4. Upper salt mass as outlined by drilling. Well locations are shown by small circles. Number adjacent to each well is for reference to well data given in Table I.

as follows: 4 samples of selenite, 2.30 g./c.c.; 5 samples of anhydrite, 2.50 g./c.c.; 4 samples of banded limestone, 2.72 g./c.c.; and 2 samples of black massive limestone, 2.73 g./c.c.

In order to obtain consolidated samples of the surface Wilcox, it was necessary to take them from creek cuts several miles from the dome. The density of these samples average 2.14 g./c.c. Gravity profiles in adjacent areas indicated a density of 1.96 g./c.c. for the surface material. However, in view of the erratic nature of both the

TABLE I. AVAILABLE DATA FROM WELLS DRILLED IN THE GRAND SALINE AREA
(Locations of wells are shown in Fig. 4)

Well Reference No.	Well	Elevation (Feet)	Depth to Cap Rock (Feet)	Depth to Salt (Feet)	Total Depth (Feet)
1	Morton Core Hole #1	383	174	213	
2	Morton Core Hole #2	403	171	232	
3	Morton Core Hole #3	419	654	668	724
4	Morton Core Hole #4	396	174	224	
5	Morton Core Hole #5	413	234	249	
6	Morton Core Hole #6	400	189	225	
7	Morton Core Hole #7 (At Mine Shaft)	391	191	215	
8	Morton Core Hole #8	402	208	229	
9	Morton Core Hole #9	403	226	242	
10	Morton Core Hole #10	403	208	225	
11	Morton Core Hole #11	415	486	495	
12	Morton Core Hole #12	415	392	400	
13	Morton Core Hole #13	419	646	651	
14	Morton Core Hole #14	418	612	No Salt	614
15	A. Wilderspin Fee No. 1		No Cap	No Salt	875?
16	Hallville Oil & Gas Co., Lindsey #2	445	No Cap	No Salt	3842
17	Hallville Oil & Gas Co., Lindsey #1	403	293?	306?	507
18	Fielder Salt Co. (Carrington #2)		212?	235	255
19	Carrington #1				
20	S. Q. Richardson #1				
21	Carington #3				
22	Southern Salt Co. (Lone Star Salt Co.)		188	235	315
23	Grand Saline Salt Co.				
24	Grand Saline Salt Co.				
25	Grand Saline Salt Co. #2		187?	235	390
26	Grand Saline Salt Co. #1		185?	245	385
27	Grand Saline Salt Co. (Water Well)			No Salt	
28	S. Q. Richardson (Drilled by Tom Marsden)			212	520
29	Grand Saline Salt Co. Artesian Water Well		No Cap	No Salt	312
30	Grand Saline Salt Co. Artesian Water Well		No Cap	No Salt	324
31	W. B. Gibson		No Cap	No Salt	450
32	Cranfill Reynolds, C. M. Alexander #1	395	No Cap	No Salt	3472
33	A. F. Richardson, Isaac Turner #1	452	No Cap	No Salt	5010
*	Morton #1			235	
*	Morton #2			235	
*	Morton #3		225	240	402
*	Morton #4		212	238	400
*	Morton #5		204	240	404
*	Morton #6		210	245	403

* Locations not available.

surface material and the gravity profiles, these densities are not considered conclusive.

Cores from the Delta #1 Gibson-Echols well and the Magnolia #1 Phillips well furnished density data on the deeper sediments. Densities of 101 samples from the Glen Rose formation in the Delta well, ob-

tained from depths of 8078 feet to 8805 feet, averaged 2.64 g./c.c.; 8 samples from the Paluxy formation in the Magnolia well, obtained from depths of 6273 feet to 6352 feet, averaged 2.53 g./c.c.; 23 samples from the Travis Peak formation in the same well, from depths of 8580 feet to 8693 feet, averaged 2.52 g./c.c.

MAGNETIC SUSCEPTIBILITIES

At the present time, the magnetic susceptibility determinations on only the samples of salt from the Grand Saline Dome have been

TABLE II. DENSITIES OF SALT, CAP ROCK AND SEDIMENTS GRAND SALINE AREA

	Material	Depth of Samples	Number of Samples	Density (g./c.c.) Range	Density (g./c.c.) Average	Remarks
Salt	Clear salt	700′	6	2.13–2.16	2.15	Fresh samples, salt mine
	Dark salt	700′	2	2.22–2.25	2.24	Fresh samples, salt mine
Cap Rock	Selenite	200′ approx.	4	2.26–2.36	2.30	Weathered (?) samples, mine dump
	Anhydrite	200′ approx.	5	2.37–2.64	2.50	Weathered (?) samples, mine dump
	Banded limestone	200′ approx.	4	2.63–2.77	2.72	Weathered (?) samples, mine dump
	Black massive limestone	200′ approx.	2	2.73	2.73	Weathered (?) samples, mine dump
Sediments	Sandy clay (Wilcox)	Surface	4	2.10–2.17	2.14	From creek cuts
	Limestones, shales, anhydrite & sands (Glen Rose)	8078–8805	101	2.37–2.86	2.64	Well cores Delta #1 Gibson-Echols
	Shales & sands (Paluxy)	6273–6352	8	2.30–2.68	2.53	Well cores Magnolia #1 Phillips
	Sands & shales (Travis Peak)	8580–8693	23	2.40–2.66	2.52	Well cores Magnolia #1 Phillips

completed and they are as follows: 4 samples of clear salt ranged from $-.51\times10^{-6}$ to $-.65\times10^{-6}$ c.g.s. units and averaged $-.56\times10^{-6}$ c.g.s. units, 1 sample of dark salt averaged $-.71\times10^{-6}$ c.g.s. units. The strength of the magnetic field in which these measurements were made, was approximately equal to that of the earth's field.

GEOPHYSICAL DATA AND INTERPRETATION

The gravity and magnetic surveys at the Grand Saline Salt Dome were made by Magnolia Party #3 during May, 1944.

The vertical and horizontal positions of the surface and subsurface stations were determined with transit and rod by ordinary field surveying methods. Maximum traverse misclosures in the vertical and horizontal surveys were 1.2 feet and 200 feet respectively.

An Askania vertical magnetometer, with a sensitivity of 20 gammas per scale division, was used in the surface magnetic survey. The instrument was read to the nearest 0.1 scale division and the calculations were carried to the nearest gamma.

A Magnolia Type 3 gravity meter, having a sensitivity of approximately 0.9 gravity unit per scale division, was used in the surface and

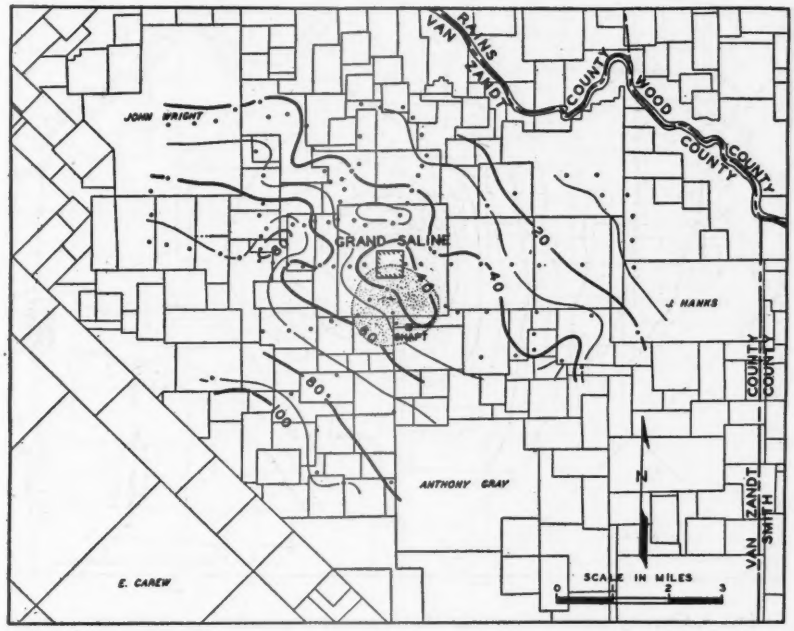

FIG. 5. Magnetic vertical intensity contours. Station locations are shown by small circles. The stippled area represents the position of the upper salt mass. Contour interval is 10 gammas.

subsurface gravity surveys. The gravity meter was read to the nearest 0.1 scale division and the gravity calculations were carried to the nearest 0.1 gravity unit. The gravity unit, which is used throughout this paper, is equivalent to 0.1 milligal.

SURFACE MAGNETIC SURVEY AND INTERPRETATION OF DATA

Locations of 116 surface gravity stations on which magnetic observations were made are shown in Fig. 5 by small circles. The usual latitude and longitude corrections were applied to the observed inten-

sities and the final vertical magnetic intensities were contoured at 10 gamma intervals. A weak minimum anomaly of 10 to 15 gammas is situated in close proximity to the upper salt mass (stippled area). Lacking data on the magnetic properties of cap and sediments at this dome, it seems probable that the anomaly is a reflection of a weak

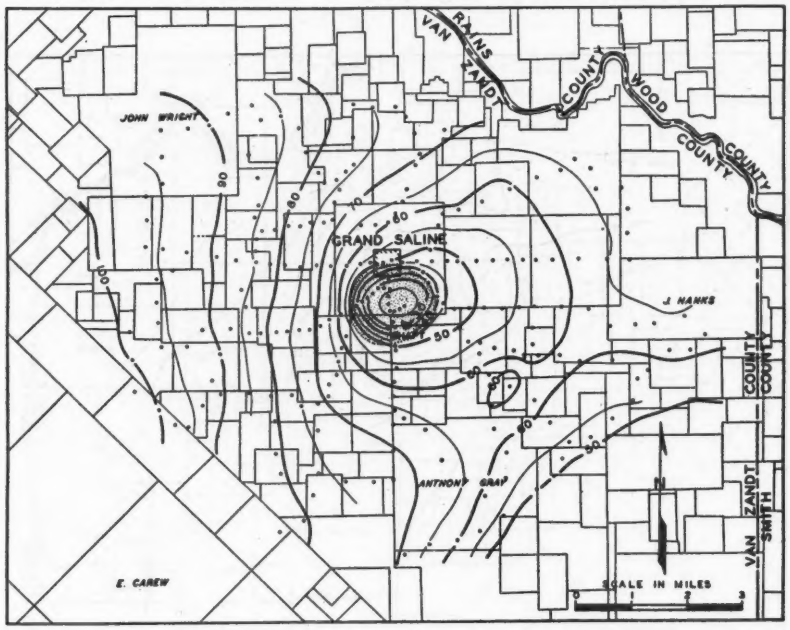

FIG. 6. Gravity contours from surface observations. Latitude, free air and Bouguer corrections applied. Station locations are shown by small circles. The stippled area represents the position of the upper salt mass. Contour interval is 5 gravity units.

negative polarization contrast between non-magnetic salt and magnetic sediments. A complete evaluation of this magnetic anomaly may be justified after the magnetic susceptibility determinations have been completed. No attempt was made to obtain subsurface magnetic observations because of the numerous magnetic interferences which obviously would be encountered in the mine.

SURFACE GRAVITY SURVEY AND INTERPRETATION OF DATA

Gravity observations were made at 244 surface stations which are shown in Fig. 6 by small circles. By application of latitude, free air, and Bouguer corrections, these observations were referred to the posi-

tion and level of a base station located on the surface at the shaft. The resulting values were contoured at 5 gravity unit intervals. The detailed surface gravity survey defined a typical salt dome pattern in Fig. 6. Approximately 38 gravity units of minimum closure were obtained and were centered roughly on the salt mass. No cap rock effect

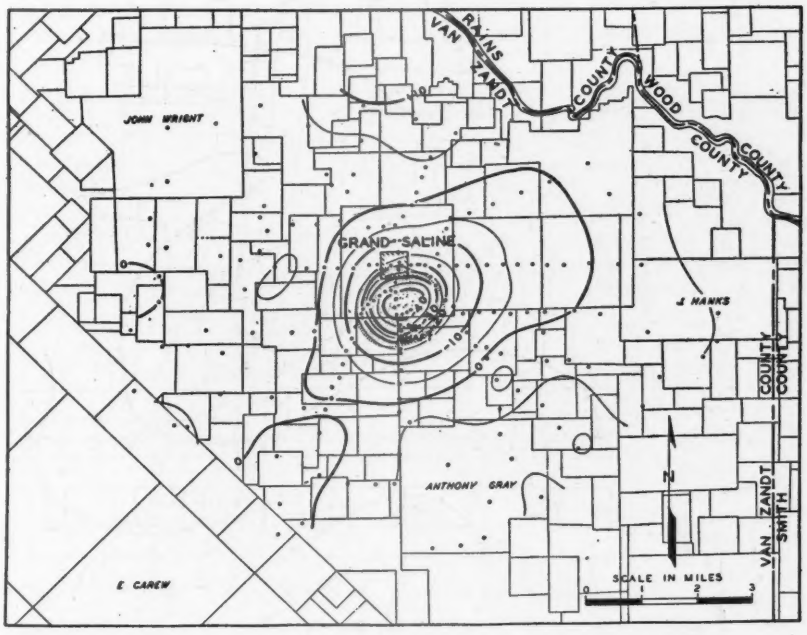

FIG. 7. Gravity contours from surface observations. Latitude, free air, Bouguer and regional corrections applied. Station locations are shown by small circles. The stippled area represents the position of the upper salt mass. Contour interval is 5 gravity units.

was apparent; however, such an effect was not expected because of the minor thickness of the cap.

In order to further evaluate the surface gravity data, the regional gravity influence was determined and eliminated from the surface observations. It was necessary to supplement the surface detailed data with previous reconnaissance data to obtain the configuration of the regional gravity pattern. The resulting local anomaly, also contoured at 5 gravity unit intervals, is shown in Fig. 7. It has approximately 43 gravity units of minimum closure situated slightly west of the observed minimum closure in Fig. 6.

SUBSURFACE GRAVITY SURVEY AND INTERPRETATION OF DATA

The subsurface gravity survey was made in the Morton Salt Company's mine, which is situated in the southeastern portion of the dome at a depth of approximately 700 feet below the surface. The subsurface

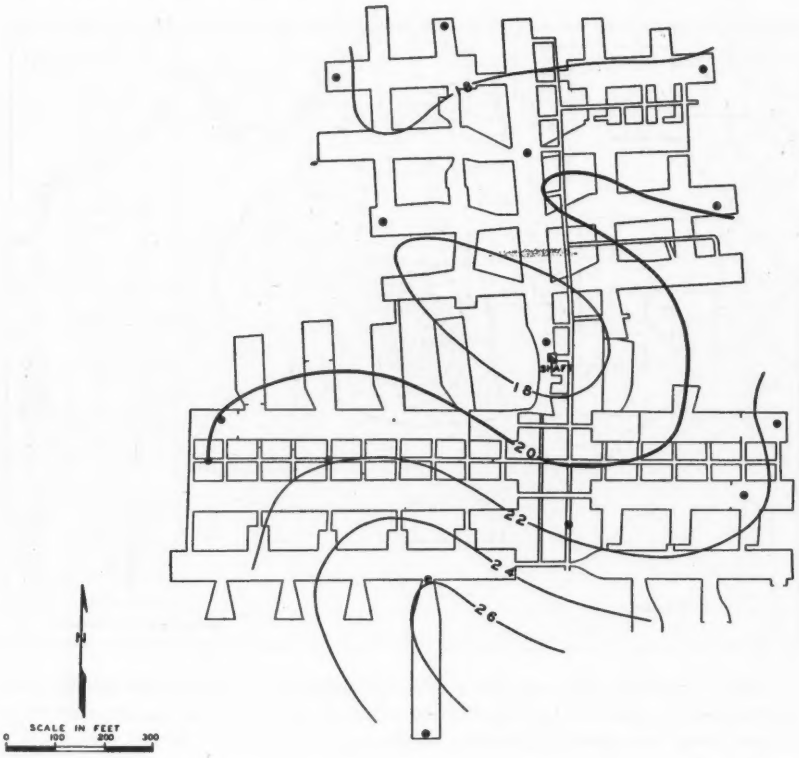

FIG. 8. Gravity contours from mine observations. Latitude, free air and Bouguer corrections applied. Station locations are shown by small circles. Contour interval is 2 gravity units.

gravity survey was tied directly to the surface gravity survey through two base stations; one stablished on the surface at the shaft, the other in the mine at the shaft. The mine workings limited the survey to a lateral extent of 1500 feet north-south, and 1200 feet east-west. A subsurface plan of the mine is given in Fig. 8, and the locations of 15 stations are indicated by the small circles. The subsurface observations were referred to the position and level of the mine base by means of

latitude, free air, and Bouguer corrections. The resulting values were contoured in Fig. 8 at 2 gravity unit intervals.

After considering the dimensions of some of the mine workings, it was apparent that the subsurface gravity observations would require a tunnel correction to compensate for the absence of the salt immediately near the stations. The mine workings in which observations were made ranged from tunnels 10 feet high, 10 feet wide, and 600 feet

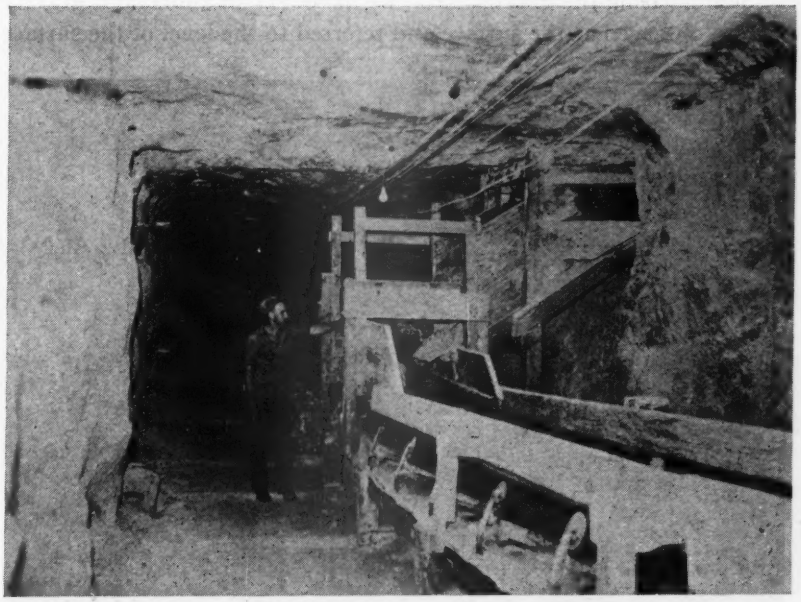

FIG. 9. 10′×10′×600′ tunnel in the Morton Salt Company's mine.

long, to rooms 90 feet high, 60 feet wide, and 600 feet long. These two extremes in the mine workings are best illustrated by photographs furnished by Mr. J. E. Hanes of the Morton Salt Company. Fig. 9 shows a section of the 10 foot by 10 foot tunnel. Fig. 10 shows a section of the 60 foot by 90 foot room. The size of the man standing at the extreme left gives a relative idea of the magnitude of this room.

In order to compute the tunnel corrections, the dimensions of the mine workings were determined to a required accuracy, and the mine relief was then represented by elevation contours extending throughout the mine workings. Allowing these contours to represent the perimeters of horizontal slabs of salt which have been removed from

these workings, the tunnel correction at each station was determined by various integration methods. These tunnel corrections ranged from 3.8 gravity units to 11.8 gravity units, and were applied to gravity observations previously corrected for latitude, free air, and Bouguer effects. The resulting values were contoured in Fig. 11 at 2 gravity unit intervals.

QUANTITATIVE INTERPRETATION OF GRAVITY DATA

Summarizing the gravity data, we have: (1) an anomalous gravity pattern observed at the surface and referred to the level of the surface

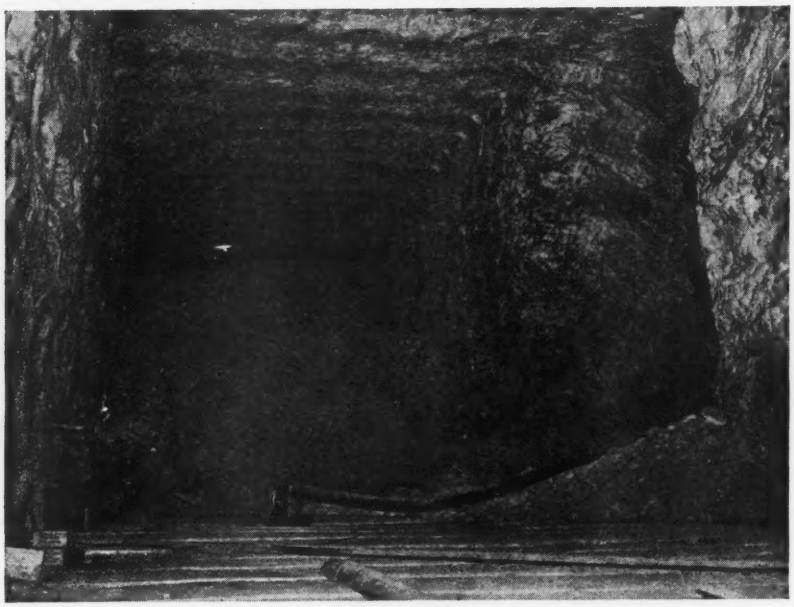

FIG. 10. 90′×60′×600′ room in the Morton Salt Company's mine.

base at the shaft by the use of free air and Bouguer corrections; (2) a portion of an anomalous gravity pattern observed in the mine and referred to the level of the mine base at the shaft by the use of free air and Bouguer corrections; and (3) we have these two observation levels inter-related by a base tie that was made between the mine base and the surface base.

Utilizing the available well data as control on the shallow dimensions of the theoretical salt mass, various assumptions were made on the densities of the sediments, and on the dimensions of the deeper

salt mass. Each assumed theoretical salt mass was divided into horizontal circular discs; and by means of solid angles, the integrated gravity effects of these discs were calculated at points on the surface level and at points on the mine level. These effects were compared to the anomalies observed at the surface level and mine level. Also, each

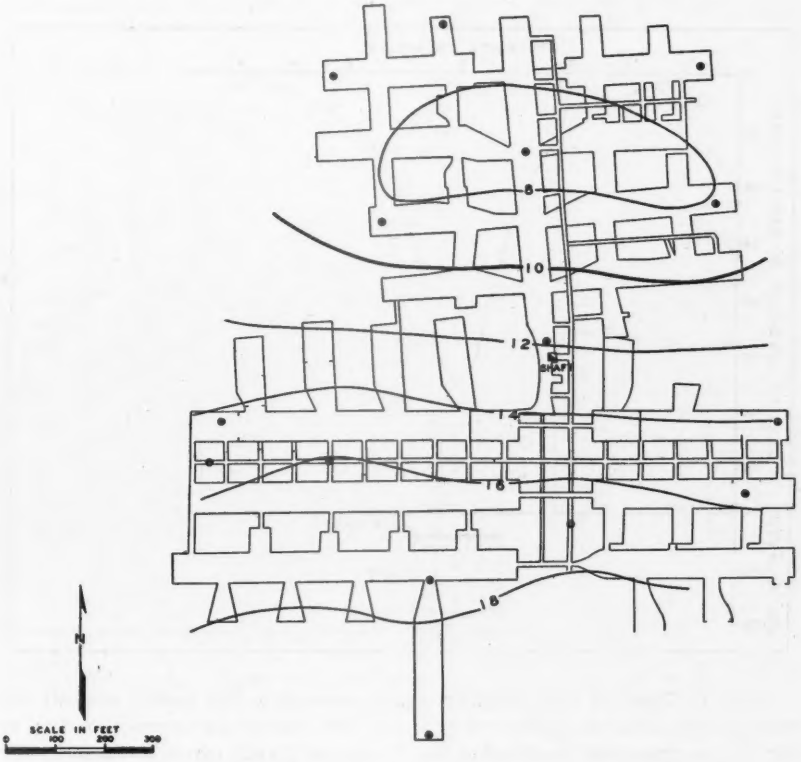

FIG. 11. Gravity contours from mine observations. Latitude, free air, Bouguer and tunnel corrections applied. Station locations are shown by small circles. Contour interval is 2 gravity units.

theoretical mass and each corresponding set of sedimentary densities were further analyzed through the use of the observed gravity difference between the surface and mine bases. Finally, after numerous modifications, a theoretical salt mass and a set of sedimentary densities were determined which reasonably satisfied all of the observed gravity data.

The upper portion of this final theoretical salt mass is shown in Fig. 12, along with the observed anomalies, and calculated gravity effects produced by the final theoretical mass. A symmetrical gravity anomaly, which was determined by averaging east-west and north-south profiles across the observed surface gravity pattern (fig. 6), is shown by the solid line. The gravity anomaly, which was determined

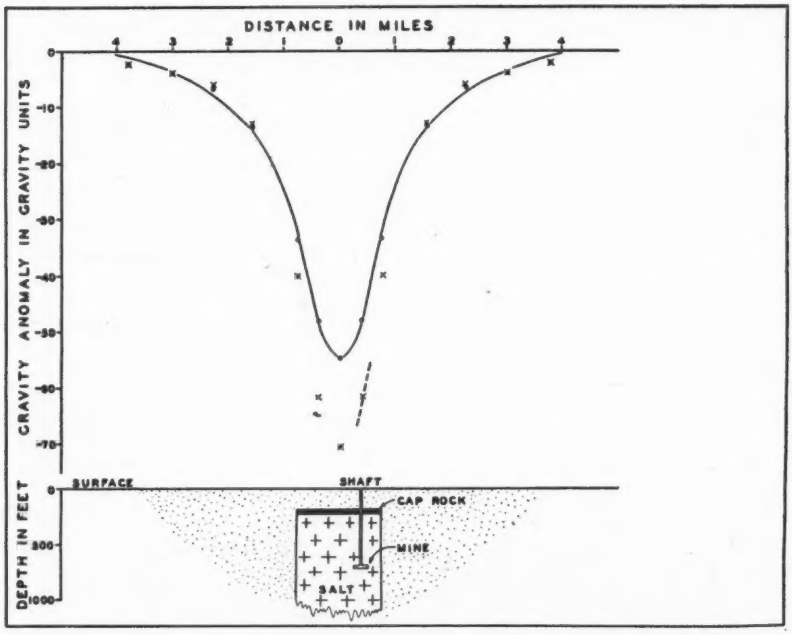

FIG. 12. Observed and theoretical gravity anomalies. The gravity anomaly observed at the surface is represented by a solid line. The gravity anomaly observed in the mine is represented by a dashed line. Calculated gravity effects produced by the final theoretical salt mass at the surface level and mine level are shown by small circles and crosses respectively.

by a single profile across the observed mine gravity pattern (fig. 11), is shown by a dashed line. The relative positions of the observed anomalies were determined by applying free air and Bouguer corrections to the observed gravity difference between surface and mine bases. The Bouguer correction eliminated the effects of infinite layers of sedimentary material which were included between the surface and mine bases. The free air correction referred the observed anomalies to

a common datum plane. Densities of the infinite sedimentary layers used in calculating the Bouguer correction were established in the final set of sedimentary densities. Calculated gravity effects produced by the final theoretical mass at the surface level are indicated by circles. Calculated gravity effects produced by the final theoretical mass at the mine level are indicated by crosses.

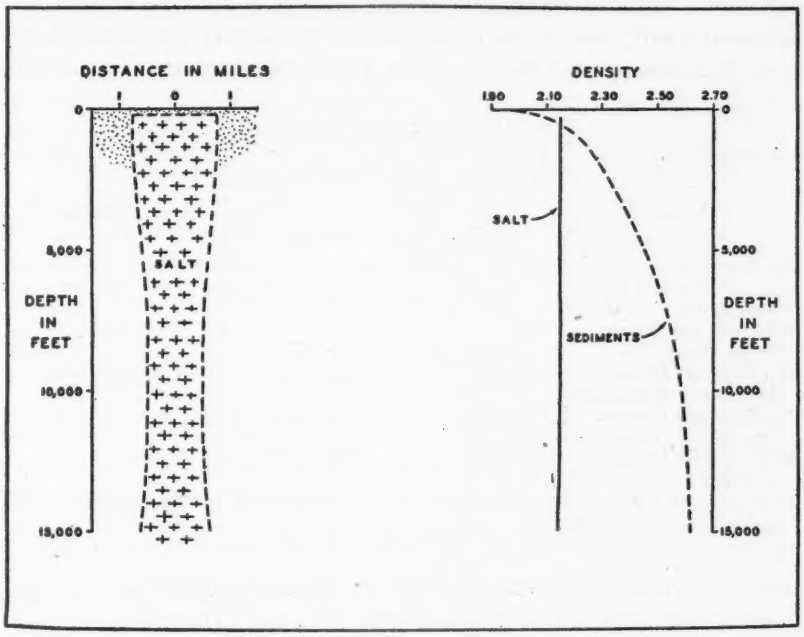

FIG. 13. Vertical cross section of the final theoretical salt mass (on left), and assumed density-depth chart (on right).

In Fig. 13, a vertical cross section of the final theoretical salt mass is shown at the left. It consists of a symmetrically-shaped salt mass having its upper and lower bases at depths of 215 feet and 15,000 feet, respectively. The assumed radii vary from 4000 feet to 2600 feet. The assumed densities utilized in the final calculations are shown in the density-depth chart to the right. Sedimentary densities were assumed to increase with depth at a rate determined by a smooth curve controlled by the density determinations. Thus, these sedimentary densities increased from 1.96 g./c.c. at the surface to 2.62 g./c.c. at 15,000

feet. A constant salt density of 2.15 g./c.c. was assumed and is represented by a vertical line in this density-depth chart.

CONCLUSION

It should be emphasized that the theoretical mass distribution is a single solution based on the existing data and on relatively simple assumptions. Other solutions undoubtedly could be obtained by making more complex assumptions on the density conditions of the sediments and salt, and on the dimensions of the deeper salt mass. However, the assumptions made and the results obtained are of a reasonable magnitude when examined in the light of geophysical and geological data obtained in this and adjacent areas. Therefore, the mass distribution as indicated by this analysis can be offered as a possible solution of the existing data.

TABLE III. DENSITIES OF CLEAR SALT

Location	Depth of Samples	Number of Samples	Density (g./c.c.)		Remarks
			Range	Average	
Grand Saline Salt Dome Van Zandt Co., Texas	700′	6	2.13–2.16	2.15	From salt mine
Winnfield Salt Dome Winn Parish, La.				2.17	From salt mine
Hockley Salt Dome Harris Co., Texas	1550′	1	2.20–2.21	2.21	From salt mine
Hockley Salt Dome Harris Co., Texas	2565′	1	2.19–2.20	2.20	Core
Hockley Salt Dome Harris Co., Texas	7750′	2	2.15–2.18	2.16	Cores
Potash Co. of America Mine Eddy Co., New Mexico	1000′	1	2.16	2.16	From potash mine

It is interesting to note the minor gravity effect at the surface due to the deeper portions of the salt mass. For example, a circular salt disc having a negative density contrast of 0.47 g./c.c., a radius of 4000 feet, a thickness of 1000 feet, and a depth of 14,500 feet, produces only −1.2 gravity units effect at the projected axis on the surface. Therefore, a 1000 foot variation in the position of the bottom of the theoretical salt mass would cause only a minor discrepancy between the theoretical and observed gravity profiles.

In order to allow a comparison of the densities of salt samples from the Grand Saline Salt Dome to those from other areas, the following average densities of clear salt are given in Table III:

Samples from the Grand Saline Salt Dome, obtained from a 700 foot depth, averaged 2.15 g./c.c.

Samples from the Winnfield Salt Dome in Winn Parish, Louisiana, averaged 2.17 g./c.c.

Samples from the Hockley Salt Dome in Harris County, Texas, obtained from a depth of 1550 feet, 2565 feet, and 7750 feet, averaged 2.21 g./c.c., 2.20 g./c.c., and 2.16 g./c.c. respectively.

Samples from the Potash Company of America Mine in Eddy County, New Mexico, obtained from a 1000 foot depth, averaged 2.16 g./c.c.

These densities compare favorably; and the data from Hockley, although inconclusive, indicate a slight decrease in density with depth. This may be due to a decrease in anhydrite content with depth.

The possibility of making observations at various heights in the shaft at Grand Saline was considered; but the instability of the lift and the interference to the mining operations prohibited these observations. Such data would allow further investigation of the actual density conditions and of the vertical change of gravity.

ACKNOWLEDGMENTS

The writers with to thank the Morton Salt Company for granting permission to make the subsurface gravity survey, and for allowing the data to be published. Much of the success of the survey can be attributed to the interest and assistance offered by Mr. J. E. Hanes, of the Morton Salt Company at Grand Saline.

We also wish to thank Mrs. Jane Artusy and Mrs. Joretta Harrington, of the Magnolia Geophysical Department, for the preparation of the maps. Finally, we wish to express our appreciation to the Magnolia Petroleum Company for permission to publish this paper.

THE NARROW-BAND RESISTANCE-COUPLED AMPLIFIER*

LAURENCE G. COWLES†

ABSTRACT

A method for the design of the amplifier coupling circuit is presented in a form permitting the selection of circuit constants directly from a specified band width, peak frequency, and peak frequency coupling loss. The design procedure is illustrated by several practical examples; the limitations of the narrow-band amplifier are discussed.

The vacuum tube amplifiers used in geophysical applications are almost exclusively resistance coupled; it is a common requirement that these amplifiers have a relatively narrow-band frequency response. In the past the design of the "tuned" resistance-coupled amplifier has been handled largely by cut-and-try methods.

Because of its importance to the geophysical equipment designer a discussion is presented here on the characteristics and limitations of the narrow-band resistance-coupled amplifier. Included are design data for the coupling circuit permitting the selection of coupling elements to produce a specified narrow-band frequency response with a minimum coupling loss.

In a recent paper[1] the author has given methods for calculating the phase and amplitude characteristics of a given coupling circuit and methods for selecting the plate resistor and operating voltages of a vacuum tube operated with a resistor in its plate circuit. For details of the theory and design methods not covered below, reference can be made to the paper cited.

Since the present discussion is primarily concerned with the coupling circuit, it will be necessary to review briefly the circuit theory of the coupling network.

THE COUPLING CIRCUIT NETWORK THEORY

The amplifier coupling circuit represented by Fig. 1 can be simplified to the circuit of Fig. 2 by making the substitution,

$$\mu' = \mu R_L/(r_p + R_L) \tag{1}$$

$$R = r_p R_L/(r_p + R_L). \tag{2}$$

* Read at the Houston meeting of the Society, 1945.

† The Texas Company, Houston, Texas.

[1] The Resistance-Coupled Amplifier, L. G. Cowles, AIEE Transactions, vol. 64, 1945, June Supplement, Paper No. 45-69.

The new constant μ' is the effective grid to plate amplification of the tube working into the external plate resistor R_L alone. The effective plate circuit resistance R is the parallel combination of R_L

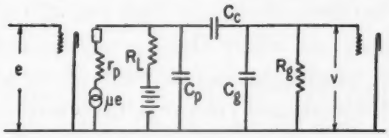

FIG. 1. Complete resistance-coupled amplifier.

and r_p. Methods for estimating r_p or for measuring μ' and R are given in the reference cited.

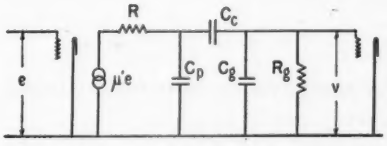

FIG. 2. Condensed resistance-coupled amplifier.

Solving the circuit equations for the complex grid to grid amplification v/e in Fig. 2, one obtains,

$$\frac{v}{e} = \mu' \frac{a\omega_0}{b\omega_0 + j(\omega/\omega_0 - \omega_0/\omega)} \tag{3}$$

where

$$a = C_c R_g$$

$$b = C_c R_g + (C_c + C_p)R + C_g R_g \tag{4}$$

$$1/\omega_0^2 = RR_g(C_c C_p + C_g C_c + C_g C_p).$$

Equation (3) can be put in the form,

$$\frac{v}{e} = \mu' \frac{a}{b} \frac{b\omega_0}{b\omega_0 + j(\omega/\omega_0 - \omega_0/\omega)} \tag{5}$$

or

$$v/\mu' e = L\,l(\omega)\epsilon^{\vartheta}. \tag{6}$$

Equation (6) represents the complex frequency characteristic of the coupling circuit. The amplitude loss at the frequency ω is given

as the product of the loss L at the peak frequency ω_0 multiplied by the relative loss $l(\omega)$ at the frequency ω.

The band width of the coupling circuit is defined here as the frequency difference between the actual high cut-off frequency ω_b and the low cut-off frequency ω_a, where the cut-off frequencies are those at which the relative amplitude $l(\omega)$ is reduced to 0.707. The relative band width B of the coupling circuit is therefore defined as

$$B \equiv (\omega_b - \omega_a)/\omega_0. \tag{7}$$

Now

$$L \equiv a/b \tag{8}$$

and if

$$m \equiv (\omega/\omega_0 - \omega_0/\omega) \tag{9}$$

equation (5) can be placed in the convenient form

$$v/e = \mu' LB/(B + jm). \tag{10}$$

Fig. 3 shows a typical frequency characteristic $l(\omega)$ as plotted on logarithmic paper with the cut-off frequencies and the quantities B and L indicated so that their mutual relationship can be readily

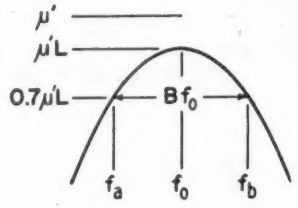

FIG. 3. Typical frequency characteristic illustrating definitions of B, L, and the cut-off frequencies.

visualized. The quantity referred to in the vacuum tube manuals as the "voltage gain,"

$$\text{V.G.} = \mu' R_g/(R + R_g) \tag{11}$$

would be located in Fig. 3 somewhere between μ' and $\mu' L$. If a vacuum tube handbook contains information for the proposed operating conditions then the indicated voltage gain can be used in equation (11) as an alternate means for calculating μ'.

Equation (10) shows that the properties of the coupling network are specified solely by the mid-band frequency ω_0, the relative band width B and the peak frequency coupling loss L. Note further that the phase shift

$$\theta = \tan^{-1}(m/B)$$

can be expressed as a function of the relative loss l, and hence θ can always be calculated directly from the amplitude-frequency characteristic, and conversely. Thus,

$$\theta = \cos^{-1} l. \tag{12}$$

One method of representing the frequency characteristic of the coupling circuit by use of a circle diagram is described by Pollack.[2] A method appealing more to the communication engineer is based on the fact that the coupling network of Fig. 2 can be represented exactly at all frequencies by the pair of simple cut-off networks shown in Fig. 4. The equivalent cut-off networks are not directly coupled, but, instead, the network on the right is assumed to be driven by a voltage equal to the voltage output of the cut-off circuit on the left. The utility of the equivalent circuit and the relation between the actual cut-off frequencies and the equivalent cut-off frequencies are given in the first reference.

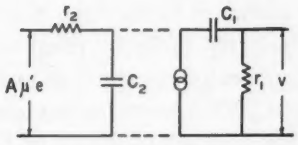

FIG. 4. Equivalent circuit.

Any frequency characteristic obtainable with the pair of equivalent cut-off circuits can be duplicated by a coupling circuit of the form represented in Fig. 1. Furthermore, any coupling circuit having three capacitors, as in Fig. 1, can be replaced exactly, so far as the frequency response is concerned, by a coupling circuit having either $C_p=0$ or $C_g=0$. Before discussing this in greater detail, it will be necessary to describe the coupling circuit design charts, Figs. 5, 6, and 7.

[2] Discussion and author's closure of a paper, Amplification Loci of Resistance Coupled Amplifiers, by A. C. Seletzky, Elect. Eng. July 1937, pp. 877–879. (In particular see discussion by Dale Pollack.)

COUPLING CIRCUIT DESIGN

The frequency characteristic of a coupling circuit may be represented as shown in Fig. 3, and, as stated above, the frequency characteristic can be completely specified by values of B, L, and ω_0. The coupling network has five parameters. Two of these are used in adjusting the circuit impedance level and the peak frequency. The three remaining parameters can be used to determine B and L within certain limitations imposed by the fact that the designer is restricted to the use of positive circuit elements.

Practically, the designer's first decision is to select R_L to give satisfactory operation of the vacuum tube. This, by equation (2), determines R. His second step is to select the succeeding grid resistor R_g and the capacitor ratios C_p/C_c and C_g/C_c so as to give values of B and L reasonably in accord with the values specified. Usually, it will be found possible to obtain the specified band width with an acceptable coupling loss. Furthermore, it is usually possible to meet the design requirements with either $C_p=0$ or $C_g=0$. The foregoing considerations have involved only ratios of the capacitors, so there can be no difficulty in obtaining a desired peak frequency. However, the practical necessity that the final design should call for capacitor sizes which can be readily purchased, forces a compromise on both the specified band width and the peak-frequency coupling loss.

Coupling-circuit elements conforming best to this array of design requirements can be selected easily by reference to Figures 5, 6, and 7. These figures show curves of constant B and L plotted against the ratios R_g/R and $(C_p+C_g)/C_c$, when for any one set of curves the ratio C_p/C_g is constant. One such set is shown in Fig. 5 for $C_g=0$, another set in Fig. 6 for $C_p=C_g$, and a third in Fig. 7 for $C_p=0$. Additional curves for other ratios of C_p/C_g are not necessary, since one can interpolate between figures with an accuracy sufficient for practical purposes. The frequency scale on the right side of these figures is used to determine the coupling capacitor C_c, which will give the specified peak frequency f_0. No approximation is involved in the construction or use of Figs. 5, 6, and 7.

The method of using the charts is best described by an example. Consider an interstage network in which it is specified that $R_L=0.15$ meg., $R_g=0.25$ meg. $C_g=0$ and $f_0=25$ cycles/sec. Assuming that the internal impedance of the tube is about 0.8 meg. we have from (2) that $R=0.125$. Suppose that the narrowest practical band is desired with a peak loss factor $L>0.3$. Reference to Fig. 5 shows that for

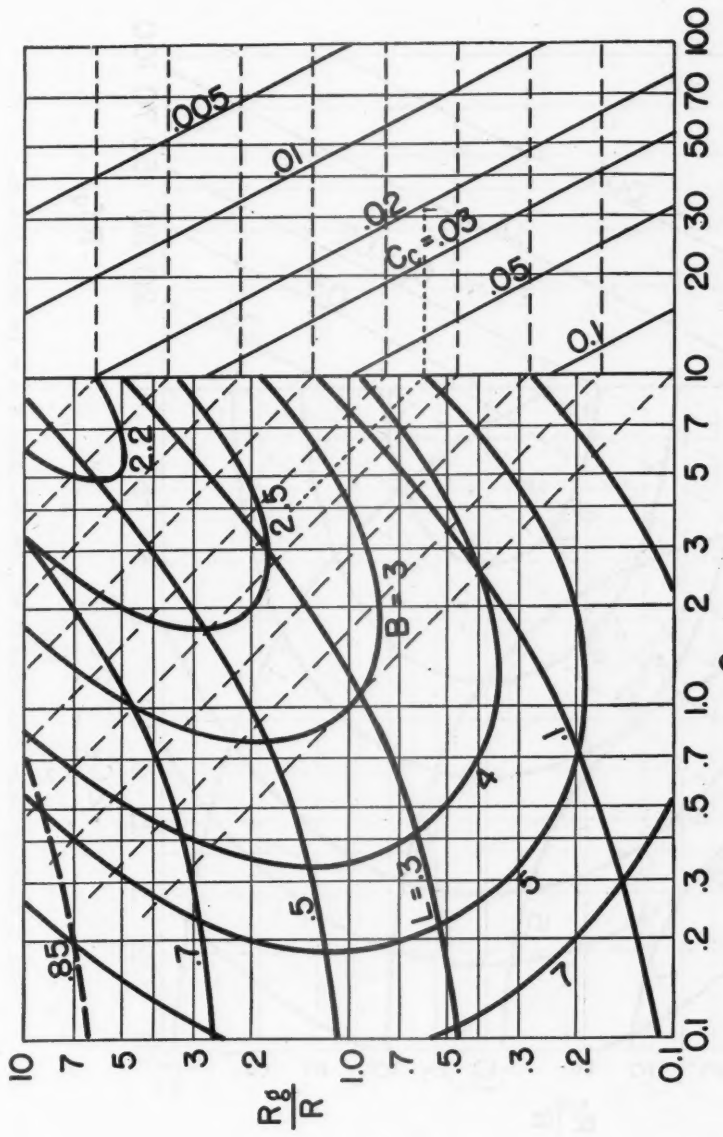

FIG. 5. Coupling design chart when C_g=0. On this chart R is in 10^6 ohms, f_0 is in cycles/second, and C_c is in microfarads.

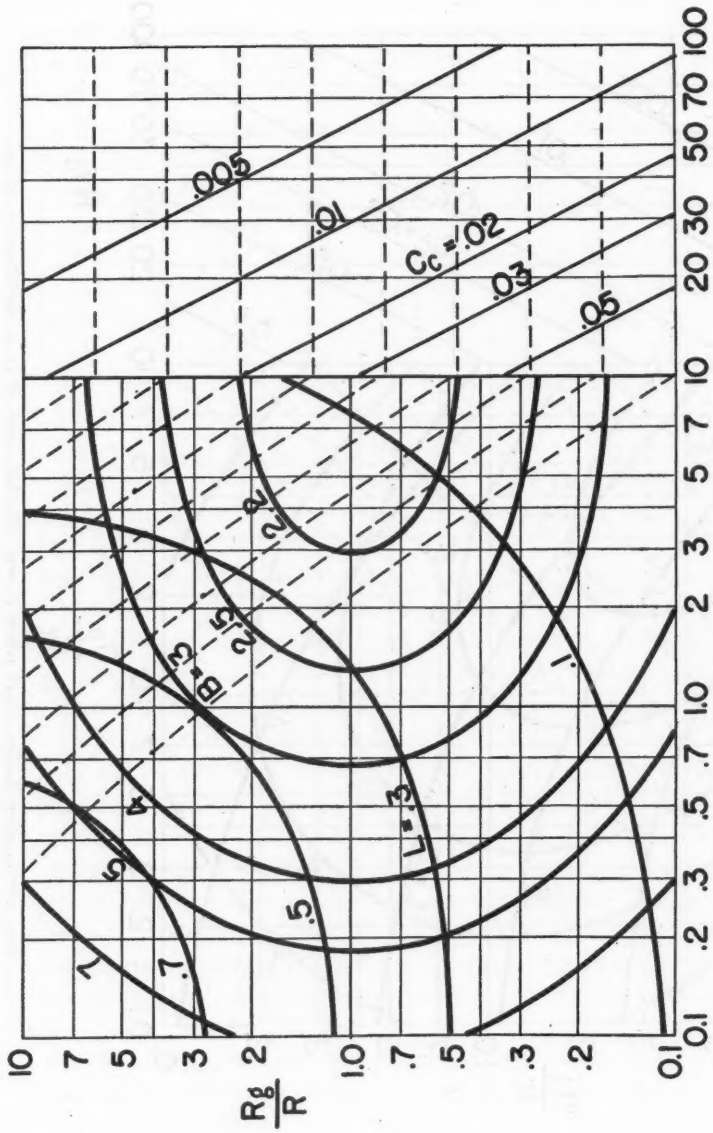

FIG. 6. Coupling design chart when $C_p = C_g$. On this chart R is in 10^6 ohms, f_0 is in cycles/second, and C_c is in microfarads.

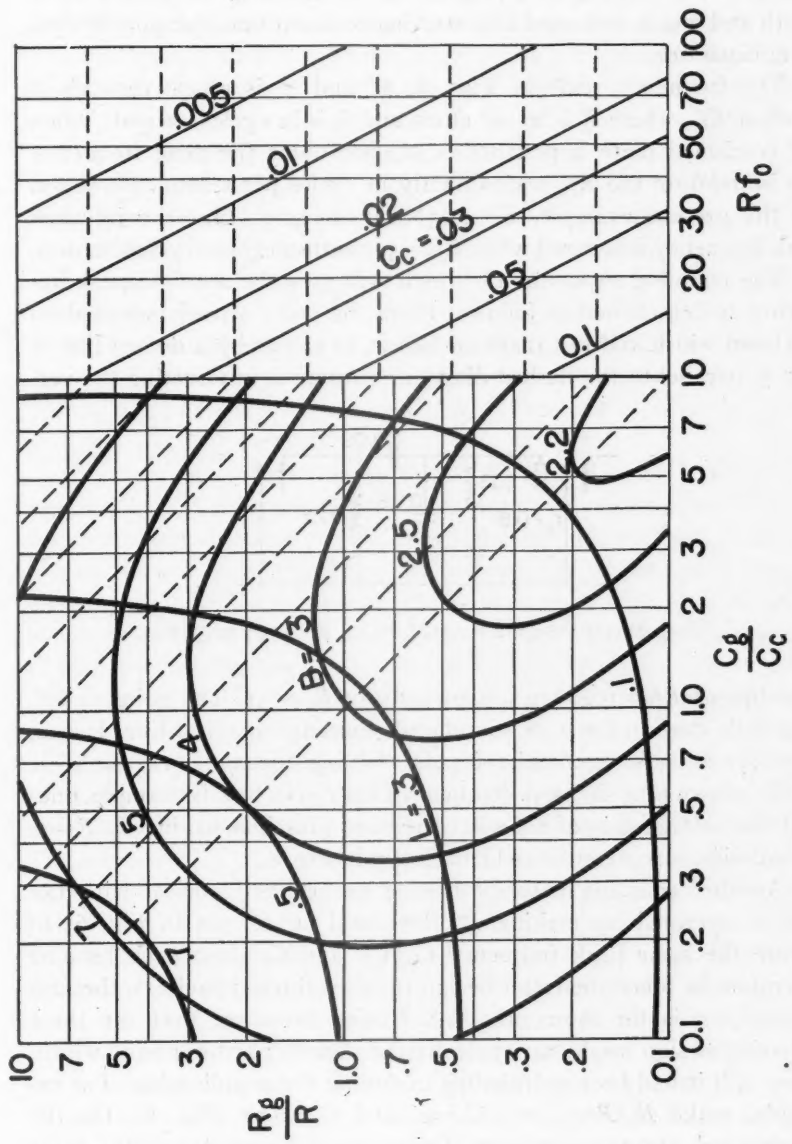

FIG. 7. Coupling design chart when C_p=0. On this chart R is in 10^4 ohms, f_0 is in cycles/second, and C_c is in microfarads.

$R_g/R=2$, B is a minimum and equals 2.45 when $C_p/C_c=3$ and $L=0.33$. The point, $R_g/R=2$; $C_p/C_c=3$, representing the desired band width and loss is now used as a starting point to find the proper coupling capacitor.

The frequency scale in Figs. 5, 6, and 7 is given through a product Rf_0, where R is in 10^5 ohms and f_0 is in cycles/second. When the combined plate impedance is 100,000 ohms the peak frequency can be read on the Rf_0 scale directly in cycles per second. However, for the present example, $R=1.25\times10^5$ ohms, so that the required peak frequency is secured when $Rf_0=31$ tenth-megohm cycles/second.

The coupling capacitor C_c which will give the required peak frequency is determined as follows: From the point already selected on the band width and loss diagram follow, as shown by a dotted line in Fig. 5, parallel to the dashed diagonal lines until intersecting the ver-

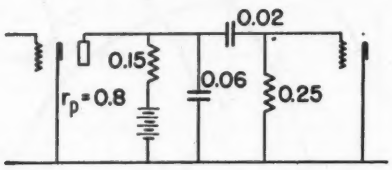

FIG. 8. Sample design. $B=2.45$, $L=0.33$, $R=1.25\times10^5$, $f_0=25$.

tical line at $Rf_0=10$, then horizontally to $Rf_0=31$. The point at $Rf_0=31$ falls close to the 0.02 microfarad coupling capacitor line. Hence, $C_c=0.02$ and $C_p=0.06$ microfarads. Solving equation (11) for μ' it can be shown that the peak frequency gain $L\mu'$ is, in this example, one-half the voltage gain of a similar flat band amplifier having $R_g/R=2$. This design is represented schematically in Fig. 8.

Another coupling network having properties identical with the first is obtained by making $R_g/R=2$ and $2C_p/C_c=2$ in Fig. 6; to secure the same peak frequency C_c, C_g, and C_p must each be 0.02 microfarads. Since the latter design requires three capacitors, the first with $C_g=0$ is the more practical. Notice, however, that the three capacitor design would have permitted a slightly narrower band width, $B=2.2$, if it had been permissible to double the coupling loss. For example, make $R_g/R=2$, $2C_p/C_c=6$, and $C_c=0.01$ (Fig. 6). On the other hand, the two capacitor design would have allowed the same band width of $B=2.45$ with the coupling loss decreased to $L=0.7$ if it had been permissible to increase the ratio R_g/R. For example, make $R_g/R=8$, $C_p/C_c=3$ and $C_c=0.01$ microfarads (Fig. 5).

Certain other factors entering the design of the coupling circuit can be explained or illustrated by the design charts. Referring again to Fig. 5, for which $C_g=0$, observe that the narrow band cannot be obtained except by making both R_g/R and C_p/C_c greater than 2 and that for a low coupling loss it is desirable that R_g/R be about 5 with C_p/C_c close to 2 or 3.

Fig. 6, for which $C_g=C_p$ shows that the narrow band can be obtained when R_g and R are approximately equal, provided one accepts about 6 db higher over-all loss. The three capacitor coupling circuit offers only an increased coupling loss and should be avoided, except when the combined plate circuit resistance R is about equal to the grid resistor.

Fig. 7, for which $C_p=0$ shows the disadvantage of placing the shunt capacitor on the grid side of the coupling capacitor C_c. The narrow band can be obtained only if R_g is less than R, whereupon the coupling loss is 15 to 20 db

It can be shown that a relative band width of $B=2$ is the narrowest obtainable and that this band width cannot be obtained with a peak frequency coupling loss of less than 6 decibels ($L=0.5$). A comparison of the response frequency characteristic of an amplifier having $B=2.5$ with one having $B=2.0$ shows that even with four identical stages relatively little is gained in narrowing the frequency characteristic by insisting on a relative band width less than $B=2.5$. Acceptance of the wider band width allows greater flexibility in the design or may permit higher values of L.

In geophysical applications it is frequently necessary to modify the frequency characteristic of an existing circuit. Figs. 5, 6, and 7 are of considerable help in understanding this problem. Assume that the circuit of Fig. 8 is given and that the shunt capacitor $C_p=.06$ is increased to 0.12 mfd. This change on Fig. 5 moves the operating point to the right on the $R_g/R=2$ line and, as can be seen, actually increases the relative band width of the coupling circuit. The high frequency cut-off has been moved to a lower frequency but only at the expense of a relatively greater decrease in low frequency cut-off. Fig. 6 shows that, if the additional .06 mfd. is placed on the grid side of the coupling capacitor, the band width is decreased but the peak frequency is shifted by a still larger factor to 13 c.p.s. If this shift in the peak frequency results in a staggering of the peak frequency of one stage with that of other stages or filters, the net effect may be far from desirable. A truly satisfactory solution may not be obtainable without changing at least two elements.

It is noteworthy that in any coupling circuit having only two capacitors the peak frequency is not changed by interchanging the capacitors or by moving the shunt capacitor from the plate to the grid side of the circuit. This suggests a convenient way of changing band width if the resulting change in the peak frequency loss is unobjectionable.

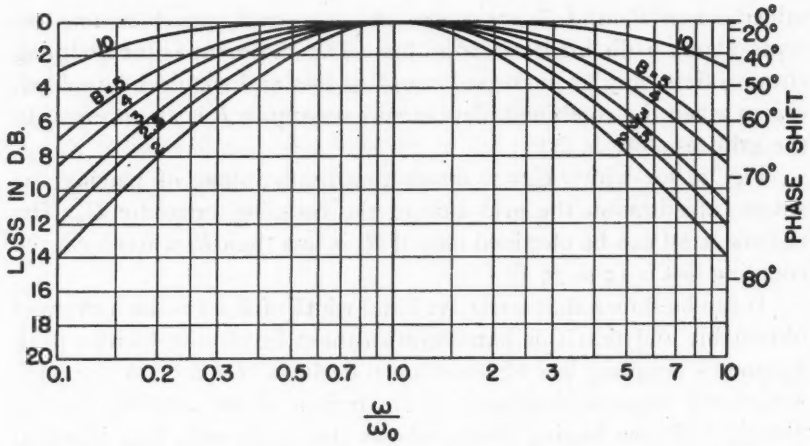

FIG. 9. Loss-frequency characteristic for a single stage amplifier. *B*, the parameter, is the relative band width.

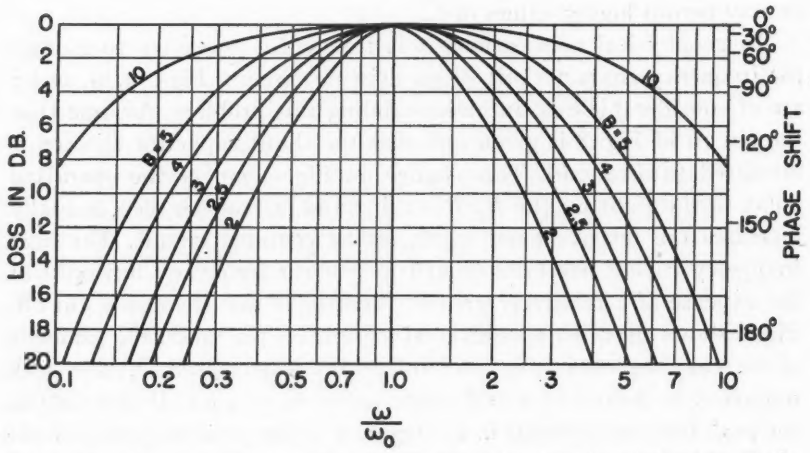

FIG. 10. Loss-frequency characteristic for amplifier with three identical stages. *B*, the parameter, is the relative band width.

RELATIVE LOSS-FREQUENCY CURVES

The relative loss-frequency curves for a single stage and for a three (identical) stage amplifier are given in Figs. 9 and 10. The curves are plotted against the relative frequency ω/ω_0. The parameter on the curves is the relative band width B. As explained above, the phase shift θ is purely a function of the relative loss, consequently θ could be plotted on the ordinate opposite the loss scale. Two or four stage amplifier characteristics can be easily plotted by using the data given on Figs. 9 and 10.

SUMMARY

A convenient method is presented for the design of coupling circuits having a specified band width, peak frequency and peak-frequency loss. Loss and phase-frequency characteristics for any one or three stage amplifier of the type under discussion are given.

The design procedure is discussed and illustrated by practical examples. It is shown that a good narrow band design is obtained by making $C_g=0$, $C_p/C_c=2$ and $R_g/R=5$. In this case the single stage cut-off frequencies are $\frac{1}{3}$ and 3 times the peak frequency. The peak frequency f_0 is approximately $1/(20C_cR)$ and the peak frequency gain is 0.7 the voltage gain obtainable in a wide band amplifier having the same plate and grid resistors.

THE RELATIVE ABUNDANCE OF THE CARBON ISOTOPES IN PETROLEUM*

S. S. WEST†

ABSTRACT

The relative abundance of the isotopes of carbon has been measured in samples of oil and gas from 32 wells in the Silica and Ellinwood Fields of Barton and Rice Counties, Kansas, and 3 wells in Oklahoma, Texas and Wyoming, as well as in surface vegetation, hydrocarbons from well cuttings, and carbon dioxide desorbed from soil. For the samples from Silica and Ellinwood Fields, $C^{12}/C^{13}=94.1\pm0.4$. Relative abundance appears to be independent of the source of petroleum, but is about 1.6% lower for vegetation. It is concluded that this quantity cannot be used to distinguish sources of petroleum and that its use to determine the origin of soil hydrocarbons requires an accuracy of measurement not hitherto attainable.

INTRODUCTION

The possibility that the relative abundances of the isotopes of chemical elements could vary according to the origin of the material in which they occur was first suggested for the case of hydrogen by the papers of Snow and Johnston,[1] Fillipova,[2] and Maillard.[3] Snow and Johnston found that butane from the fractional distillation of a natural gas concentrate from a Burbank, Oklahoma, well contained 35% more deuterium (hydrogen of atomic weight 2) than normal, which caused an added excess of 6.1 parts per million in the density of the water of combustion. (The deuterium in normal water corresponds to a density excess of about 16 parts per million.) Fillipova found an added excess density of 11 parts per million in the water of combustion of Makhach-Kala motor petroleum, which corresponds to an excess of 70% of deuterium above normal. Maillard found approximately 100% excess of deuterium in the water of combustion of three gasolines. The second and third references give density excesses twice as great as any recorded for other substances. However, the technique of measurement is rather difficult, and later workers have thrown some doubt on these results, although none has actually repeated the experiment.

It might have been thought that only hydrogen, the lightest ele-

* Read at Tulsa meeting, 1945.

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[1] R. D. Snow and H. L. Johnston; Science *80*, 210 (1934).

[2] N. S. Fillipova; Comptes Rendus (Doklady) de l'Acad. des Sciences, U.S.S.R., *3*, 1, p. 29 (1935).

[3] A. Maillard; Comptes Rendus *203*, 804 (1936).

ment, would show measurable variations in isotopic abundance, but similar evidence exists for lead, potassium, and carbon. A. O. Nier and his coworkers[4] measured the abundance of the lead isotopes in many samples of radiogenic lead and of common lead from sources throughout the world. Measurements were made by bombarding lead iodide vapor in a mass-spectrometer, and the data thus obtained were used to calculate the ages of the specimens. In radiogenic lead, the isotope of mass 204 was rarely present as more than 0.1% of a sample, which might consist chiefly of the isotope of mass 206 or chiefly of that of mass 208. The abundance of the isotope of mass 207 varied by as much as 15 times among the samples. In common lead, however, mass 204 predominates, and none of the other three isotopes varied by more than about 40% in its average abundance. Extensive tables of these results are given in Nier's papers.

A. K. Brewer[5] found small differences in the abundance-ratio of the major potassium isotopes of atomic weights 39 and 41 in twelve samples from various sources. However, the root-mean-square deviation of the abundance-ratio was only 0.3%. Only one sample had a deviation larger than three times this value, the deviation being 2.7% in this case. The radioactive isotope of atomic weight 40 occurs as about 0.01% of potassium, and so was below the limit of Brewer's measurements. However, it has more recently been shown by Brewer[6] and by Smythe[7] that the abundance of K^{40} does not vary by more than 10%, even under the most extreme conditions.

Carbon has been investigated by Nier and Gulbranson[8] and by Murphey and Nier[9], whose results are shown in Table I. The ratio of the concentration of carbon of atomic weight 12 to that of atomic weight 13 is denoted by C^{12}/C^{13}.

In both papers determinations are stated to be reproducible to 0.5%. Maximum variations are about 4%, so that the phenomenon of the variation of the isotopic abundance-ratio offers the possibility of a new method for determining the origin of carbon compounds in nature.

[4] A. O. Nier; Jour. Am. Chem. Soc. *60*, 1571 (1938).
A. O. Nier; Phys. Rev. *55*, 153 (1939).
A. O. Nier, R. W. Thompson and B. F. Murphey; Phys. Rev. *60*, 112 (1941).
[5] A. K. Brewer; Jour. Am. Chem. Soc. *58*, 365 (1936).
[6] A. K. Brewer; Phys. Rev. *55*, 669 (1939).
[7] W. R. Smythe; Phys. Rev. *55*, 361 (1939).
[8] A. O. Nier and E. A. Gulbranson; Jour. Am. Chem. Soc. *61*, 697 (1939).
[9] B. F. Murphey and A. O. Nier; Phys. Rev. *59*, 771 (1941).

PURPOSE AND SCOPE OF INVESTIGATION

Available data on the abundance-ratio of carbon isotopes indicated that one might expect to find differences from one type of petroleum to another and perhaps a difference between soil-gas from petroleum and soil-gas produced at the surface by decaying vegetation. In the former case, one could use such a difference to distinguish the sources of production, and in the latter case one could substitute the measurement of a property of soil-gas for the measurement of quantity which

TABLE I. RELATIVE ABUNDANCE OF CARBON ISOTOPES AS OBSERVED IN PREVIOUS INVESTIGATIONS

Class	Material of Sample	C^{12}/C^{13}	
		Nier & Gulbranson	Murphy & Nier
Igneous	graphite	89.8	90.2
	meteorite	89.4	89.8–92.0
	diamond	89.0	—
Limestones	sedimentary rocks	87.9–88.6	88.8–89.4
	marine shell	88.7	89.5
Plant sources	coal	91.8	91.3–92.0
	bituminous shales	—	92.1–92.7
	torbanite and kerosene shales	—	91.3–92.0
	wood	91.5	91.6–92.2
Petroleum		91.2	92.0–92.8
Miscellaneous	dry ice	91.2	—
	clam flesh	90.1	—
	Lycopodium spores	—	93.1
	"Balkashite algae"	—	92.8

is now used. (The greatest difficulty in the application of soil-gas prospecting has been the alteration of the adsorptive power of soil by its environment, and it was hoped that a method based on isotopic abundance would permit one to avoid errors introduced by varying adsorption.) There were also the interesting questions of whether the abundance-ratio of carbon varied with molecular weight of the hydrocarbon containing it and whether the distribution of the heavy carbon isotope among hydrocarbon molecules of a given structure was purely random.

It was decided that the first phase of the investigation should consist of the measurement of the abundance-ratio of the carbon isotopes

in each of several light fractions of each of a number of samples of natural gas or oil from wells in a single field, extending the measurement to wells in other fields, if no large random variations were found in the first set of samples. For this purpose we required a field in which oil was being produced from a single horizon, with no other oil existing above or below, and about which were other fields producing from the same horizon. Thus the origin of the samples of gas and oil could be known with considerable certainty, and the variation of the abundance-ratio could be observed over a wide area under simple conditions. As such a group were selected the Ellinwood, Silica, Richardson, Aynsworth, Pawnee Rock, Zook, Stoltenberg, and Marshall fields (of Barton, Rice, Stafford, Pawnee, Ellsworth, and Ellis counties, Kansas). All these fields produce only from the Arbuckle "silicious lime," of Cambro-Ordovician age. Samples were obtained from the Silica and Ellinwood fields, which are located centrally in the group. Relative abundance was measured in 31 oil samples and 3 gas samples taken from 32 wells in these fields.

Measurements were also made on relative abundance in oil from three wells in Oklahoma, Texas and Wyoming, in hydrocarbons released from the cuttings of a shallow well in Tulsa, in three samples of vegetation, and in carbon dioxide adsorbed on soil samples. Attempts to separate from soil gas large enough quantities of hydrocarbons for measurement had to be given up when it was found that the development of a suitable technique of separation would take longer than was justified.

EXPERIMENTAL TECHNIQUE

1. FRACTIONATION

By means of fractional distillation on a Podbielniak apparatus, propane and n-butane were separated in the pure state from each sample of gas or oil. The purity of each fraction was better than 99%. These two hydrocarbons were the only ones which could be obtained from every sample, although methane and ethane were also collected from five samples, and isobutane and the pentanes from a few others. The separated hydrocarbons were collected in glass flasks with stopcocks and ground joints, and were thus transferred to the combustion apparatus. Alternatively, the flask could be attached directly to the mass-spectrometer for analysis.

The isotopic abundance-ratio was measured separately for each fraction.

2. COMBUSTION

Each pure fraction of an oil sample was burned by passing the hydrocarbon gas over an incandescent platinum wire in an excess of oxygen. Carbon dioxide thus produced was condensed by immersing the lower end of the combustion chamber in liquid air. Excess oxygen and unburned gas were then pumped off. The liquid air was replaced by a mixture of dry ice and alcohol, and carbon dioxide was permitted to vaporize into the combustion chamber, while water (and n-butane in the case of that fraction) was retained on the cold wall. A stopcock was then opened to a sample flask which had previously been evacuated and immersed in liquid air. When all carbon dioxide had been condensed in the sample flask, the stopcock was closed, and the flask removed to the mass-spectrometer.

Oxygen for combustion was obtained from a tank of the Linde Air Products Co., the same tank being used throughout the work. It was purified by passing it through a trap filled with glass-wool and immersed in liquid air.

Fairly accurate measurements of abundance-ratio can be made on propane without burning. As will be shown later, the values thus obtained are nearly the same as those measured in carbon dioxide from the burned gas, which provides a check on the combustion procedure.

The method of combustion is essentially the one used previously by Nier[10] for methane. In the case of methane, one must work with CO_2 because of the fact that the water vapor usually present yields $O^{16}H^+$, which has the same mass as the ion $C^{13}H_4^+$. In general, the purpose of burning the hydrocarbon gas is to obtain as simple a mass-spectrum as possible, whose form is independent of the structure of the hydrocarbon molecule. By this means, the abundance-ratio can be measured directly without the assumption of a random distribution of C^{13}, since the CO_2 molecule contains only one carbon atom.

3. MASS-SPECTROMETER

The mass-spectrometer used in this research was very similar to that described by Nier[11] a few years ago. However, our instrument was made to record automatically on a Leeds and Northrup "Speedomax" recorder by mounting a dual photocell on the pen-carriage, as suggested by Pompeo and Penther.[12] The light-beam reflected from the

[10] A. O. Nier; Phys. Rev. *56*, 1010 (1939).
[11] A. O. Nier; R. S. I. *11*, 212 (1940).
[12] D. J. Pompeo and C. J. Penther; R. S. I. *13*, 218 (1942).

galvanometer of the DuBridge and Brown[13] electrometer circuit was focussed on this photocell, which caused the motor of the recorder to move the pen-carriage to restore the condition of balance and follow the galvanometer spot. A helical potentiometer was geared to the chart-drive as a control for the stabilized voltage source, so that the ion accelerating voltage could be varied in proportion to the movement of the chart.

The accuracy to be expected from measurements made with this apparatus can be estimated from determinations of the relative abundances of the neon isotopes in 37 samples of gas drawn from the same reservoir. According to a method developed by the Stanolind Oil and Gas Company, neon was mixed with other gases as an internal standard, and the records from which its mass-spectrum was measured were taken over a period of eleven weeks. Table II gives the averages of these relative abundances, deviations of individual observations from the average, and values determined by other observers, one set from the International Table of Stable Isotopes[14] and the other measured by N. D. Coggeshall and published in a paper by Jordan and Young.[15] The heights of the peaks on the record which represented the abundances of Ne^{20} and Ne^{22} were between 40 and 90% of full chart-width. while the height of the peak for Ne^{21} averaged about 2% of chart-width. The agreement of our values with the two sets from the literature is at least as good as the agreement of these two sets themselves. Errors in later data on the mass-spectrum of CO_2 should be less than the deviations listed in Table II, for this mass-spectrum was recorded three to six times for each sample and the average used in the final tabulation.

4. MASS-SPECTRUM OF CO_2

The mass-spectrum of carbon dioxide consists of three peaks. The peak at mass 44 is composed of $C^{12}O_2^{16+}$ ions, that at mass 45 of $C^{12}O^{16}O^{17+}$ ions and $C^{13}O_2^{16+}$ ions, and that at mass 46 of $C^{12}O^{16}O^{18+}$ ions with a very small contribution of $C^{13}O^{16}O^{17+}$ and $C^{12}O^{17+}$. The abundances of the ions of masses 44, 45 and 46 stand approximately in the proportion 1000:11.5:4.0.

Because of scattering of ions by gas in the mass-spectrometer, the edge of the peak at mass 44 extends some distance toward higher

[13] L. A. DuBridge and Hart Brown; R. S. I. *4*, 532 (1933).
[14] International Table of Stable Isotopes; R. S. I. *7*, 334 (1936).
[15] E. B. Jordan and L. B. Young; Jour. Appl. Phys. *13*, 526 (1942).

masses, producing at mass 45 a background which amounted usually to 2 to 5% of the smaller peak. This background varied approximately as the 1.73 power of the gas pressure. Correction was made quite accurately by drawing the background on the record and measuring from that base-line. A better pumping system would no doubt have removed this defect almost completely.

The ratio of the abundances of CO_2 ions of masses 44 and 46 is almost identical with the abundance-ratio of the oxygen isotopes of atomic weights 16 and 18. This abundance-ratio was computed from

TABLE II. RELATIVE ABUNDANCES OF NEON ISOTOPES

Abundance Ratio	Average Observed Ratio	Deviations from Average				Ratio from Other Observers	
		% of Observed Value		% of Chart Width		Int. Table	Coggeshall
		R.M.S.	Max.	R.M.S.	Max.		
$\frac{10\,Ne^{22}}{Ne^{20}}$	1.039	0.86	2.0	0.56	1.3	1.082	1.033
$\frac{1000\,Ne^{21}}{Ne^{20}}$	3.13	9.5	26.0	0.19	0.5	3.0	3.5

our records, and that for the oxygen isotopes of atomic weights 17 and 18 was determined by separate measurement on the oxygen used for combustion. The results were as follows:

$$O^{16}/O^{18} = 494 \pm 6 \qquad O^{18}/O^{17} = 5.0.$$

These compare well with the following values obtained by B. F. Murphy[16] for commercial oxygen from two different tanks:

$$O^{16}/O^{18} = 500 \pm 15 \qquad O^{18}/O^{17} = 4.9 \pm 0.2.$$

The abundance-ratio of the carbon isotopes is therefore given by

$$C^{12}/C^{13} = \frac{\text{Abund. of mass } 44}{(\text{Abund. of mass } 45) - 0.20\,(\text{Abund. of mass } 46)}.$$

In order to obtain the same precision of measurement for the peaks of masses 44 and 45, which differ by a factor of 90, one must

[16] B. F. Murphey; Phys. Rev. *59*, 320 (1941).

change the sensitivity of the instrument by a similar factor in going from one to the other. Previous investigators have done this by changing the grid resistor of the electrometer tube, thus maintaining the circuit in the same operating condition. In the present case, however, it was more convenient to change the sensitivity of the galvanometer by means of an Ayrton shunt, the grid resistor being kept at a constant value of 20,000 megohms. Because of the curvature of the electrometer-tube characteristic (as well as errors in the shunt), it was therefore necessary to calibrate the electrometer by introducing a variable known voltage into the grid circuit and observing the deflection of the recorder pen as a function of input voltage for the 1.0, 0.1, and 0.01 ranges of the Ayrton shunt. Corrections by this calibration amounted to only a few percent.

DATA ON THE RELATIVE ABUNDANCE OF THE CARBON ISOTOPES

1. SAMPLES FROM SILICA AND ELLINWOOD FIELDS

Measured values of the ratio C^{12}/C^{13} of the abundances of the carbon isotopes are given in Table III for samples from 32 wells in the Silica and Ellinwood Fields of Barton and Rice Counties, Kansas. Three gas samples are included, but in all other cases the samples were of oil.

The differences between the values for propane and butane are not large enough to be significant. The average abundance-ratio for each fraction is 94.13, though the average difference between fractions is 0.8. In 16 cases the ratio is greater for propane than for n-butane and in 12 cases it is less. The maximum difference in abundance-ratio between fractions is 1.7.

The root-mean-square deviation of the average abundance ratio for each well from 94.1 (the mean of all determinations) is 0.52. This is somewhat less than the deviation to be expected from instrumental causes alone, as determined by the data of Table II. The maximum deviation is 1.1, so the deviations may be considered as wholly random.

Fig. 1 is a map of Silica and Ellinwood Fields, showing the locations of the wells from which the samples were taken. Each value within a circle is the average of C^{12}/C^{13} for propane and n-butane fractions of the sample taken from the well at that place. Since variations from well to well are of about the same magnitude as differences between fractions in Table III, no systematic variation of abundance-ratio over the field can be said to exist.

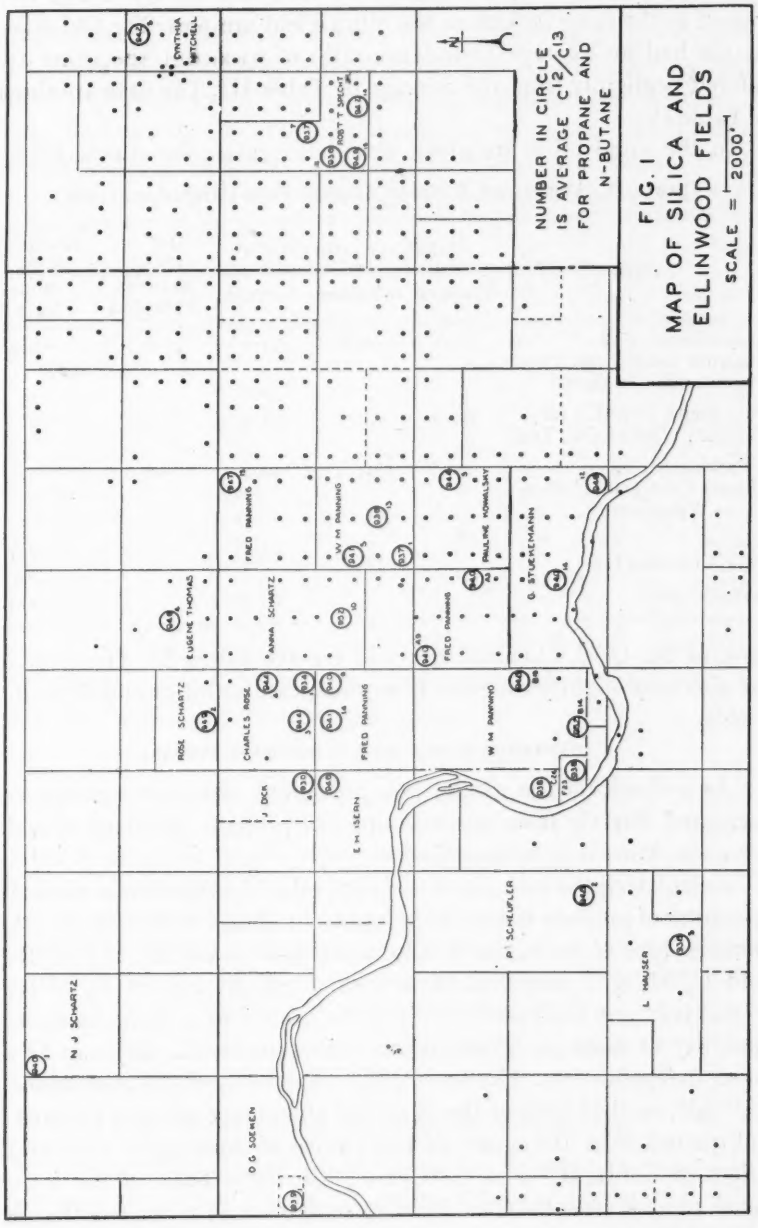
TABLE III. ABUNDANCE RATIO IN SAMPLES FROM SILICA AND ELLINWOOD FIELDS

Source	Abundance Ratio C^{12}/C^{13}			Diff. of C^{12}/C^{13} between Fractions	Deviation of Average from 94.1
	Propane	n-Butane	Average		
W. M. Panning 1 (gas)	93.5	93.1	93.3	0.4	−0.8
W. M. Panning 1 (oil)	94.0	94.0	94.0	0	−0.1
R. T. Specht 7 (gas)	94.3	93.1	93.7	1.2	−0.4
W. M. Panning 5 (gas)	93.2	94.4	93.8	−1.2	−0.3
W. M. Panning 5 (oil)	94.2	94.6	94.4	−0.4	0.3
W. M. Panning F23	93.6	94.0	93.8	−0.4	−0.3
W. M. Panning B14	96.0	94.3	95.2	1.7	1.1
W. M. Panning 13	93.6	93.5	93.6	0.1	−0.5
E. H. Isem 1	94.0	95.2	94.6	−1.2	0.5
J. Dick 4	92.9	93.2	93.0	−0.3	−1.1
C. Rose 1	93.5	93.2	93.4	0.3	−0.7
C. Rose 3	94.5	94.3	94.4	0.2	0.3
C. Rose 4	94.2	94.5	94.4	−0.3	0.3
W. M. Panning C24	94.0	93.7	93.8	0.3	−0.3
C. Mitchell 5	94.3	94.1	94.2	0.2	0.1
F. Panning 8	93.9	94.0	94.0	−0.1	−0.1
F. Panning 14	94.2	94.0	94.1	0.2	0
R. T. Specht 12	93.1	94.1	93.6	−1.0	−0.5
R. T. Specht 14	94.0	94.5	94.2	−0.5	0.1
R. T. Specht 15	—	94.8	94.8	—	0.7
N. J. Schartz 1	—	94.0	94.0	—	0
O. G. Soeken 1	—	93.9	93.9	—	−0.2
E. Thomas 4	95.0	94.3	94.6	0.7	0.5
F. Panning 15	—	94.7	94.7	—	0.6
R. Schartz 2	—	94.9	94.9	—	0.8
P. Scheufler 2	—	94.6	94.6	—	0.5
G. Stueckemann 12	94.9	94.4	94.6	0.5	0.5
G. Stuechemann 14	93.9	94.0	94.0	−0.1	−0.1
Anna Schartz 10	95.7	94.6	95.2	1.1	1.1
W. M. Panning B19	94.0	95.2	94.6	−1.2	0.5
L. Hauser 5	93.6	93.7	93.6	−0.1	−0.5
P. Kowalsky 5	94.9	94.0	94.4	0.9	0.3
F. Panning A9	94.5	93.6	94.0	0.9	−0.1
F. Panning A3	94.2	93.8	94.0	0.4	−0.1
Average	94.13	94.13	94.16	0.8	
R.M.S. deviation					0.52
Maximum deviation				1.7	1.1

In the case of the five samples which yielded methane and ethane as well as propane and n-butane, the abundance-ratio for ethane is 0.9% and that for methane 1.0% lower than the average of the two heavier fractions.

2. SAMPLES FROM OTHER LOCATIONS

Oil samples from three wells located in Pottowatomie Co., Okla-


NUMBER IN CIRCLE
IS AVERAGE C12/C13
FOR PROPANE AND
N-BUTANE
FIG. 1
MAP OF SILICA AND
ELLINWOOD FIELDS
SCALE = 1/2000'
CYNTHIA MITCHELL
ROBT T SMITH
FRED PANNING
W M PANNING
PAULINE ROMILLY
G STUEMEMANN
EUGENE THOMAS
ANNA SCHARTZ
ROSE SCHARTZ
CHARLES ROSE
J DICK
E M ISERN
P SCHEUFLER
L HAUSER
N J SCHARTZ
O G SOEMEN

homa, in Winkler Co., Texas, and in Carbon Co., Wyoming, were treated in the same fashion as the Silica Field samples. The Oklahoma sample had an average abundance-ratio of 93.2, but the other two differed negligibly from the average of Table III. The data are shown in Table IV.

In the same table are given abundance-ratios for ethane from a

TABLE IV. ABUNDANCE RATIO IN SAMPLES FROM OTHER LOCATIONS

Source	Abundance ratio C^{12}/C^{13}			Diff. of C^{13}/C^{12} between Fractions	Deviation of Av. from 94.1
	Propane	n-Butane	Average		
Mary Bleeker 1 oil (Shawnee Lake Field, Pottawatomie Co., Okla.)	93.1	93.2	93.2	−0.1	−0.9
Sealy Smith Found. 1 oil (Wildcat, Winkler Co., Tex.)	94.3	93.5	93.9	0.8	−0.2
J. Parkinson 1 oil (Cooper Cove field, Carbon Co., Wyoming)	93.8	94.4	94.1	−0.6	0
Ethane (Ohio Chemical Co.)			93.5		−0.7
Acetaldehyde			93.7		−0.4

tank of the Ohio Chemical Co. and for acetaldehyde. These values are also only slightly different from the mean for Silica and Ellinwood Fields.

3. COMPARISON OF BURNED AND UNBURNED PROPANE

As a check on the combustion procedure, abundance-ratios were measured directly from seven samples of propane, portions of which were also burned to carbon dioxide.

Calculating the isotopic abundance-ratio of carbon from the mass-spectrum of propane is somewhat less direct than for the case of carbon dioxide. Ions of molecular weight 44 consist of $C_3^{12}H_8^{1+}$, $C_2^{12}C^{13}H_7^{1+}$, and $C_3^{12}H_6^{1}H^{2+}$, and ions of molecular weight 45 are $C_2^{12}C^{13}H_8^{1+}$, $C^{12}C_2^{13}H_7^{1+}$ and $C_3^{12}H_7^{1}H^{2+}$. Only $C^{12}C_2^{13}H_8^{1+}$ ions exist in measurable quantity at mass 46. Since all corrections are small, they can be applied independently. The ion $C_3^{12}H_7^{1+}$ has 80% of the abundance of $C_3^{12}H_8^{1+}$, so that 80% of the observed abundance of mass 45 must be subtracted from the observed abundance of mass 44 to remove the effect of $C_3^{12}H_6^{1}H^{2+}$ and $C_2^{12}C^{13}H_8^{1+}$. Similarly 80% of the ions of mass 46 must be subtracted from those of mass 45 to remove the effect of $C^{12}C_2^{13}H_7^{1+}$ ions. Finally, since deuterium is 1/6900 of all hydrogen,

we must subtract 0.12% of the observed abundance of mass 44 from that of mass 45 to remove the effect of $C_3^{12}H_7^1H^{2+}$ ions. The adjusted abundances of the ions of masses 44, 45 and 46 will then represent only the effect of the C^{13} isotope, corresponding to ions of mass 44 which contain only C^{12}. When an abundance of 10,000 is assumed for ions of mass 44, as in Table V, the result of these corrections is to subtract approximately 7 units from the abundance of mass 45 and add 0.1 unit to that of mass 46.

TABLE V. COMPARISON OF BURNED AND UNBURNED PROPANE

Source	Relative Abundance of Propane Ions					C^{12}/C^{13}		
	Mass 44	Mass 45		Mass 46		from propane	from CO_2	Difference
		obs.	*corr.*	*obs.*	*corr.*			
W. M. Panning B-19	10,000	326	319	3.6	3.7	94.0	94.0	0
G. Stueckemann 12	10,000	328	321	4.1	4.2	93.2	94.9	−1.7
G. Stueckemann 14	10,000	331	324	4.3	4.4	92.1	93.9	−1.8
Anna Schartz 10	10,000	327	320	4.0	4.0	93.5	95.7	−2.2
L. Hauser 5	10,000	328	321	3.8	3.9	93.2	93.7	−0.5
Sealy Smith Found. 1	10,000	327	320	3.8	3.9	93.5	94.3	−0.8
J. Parkinson 1	10,000	324	317	3.3	3.3	94.6	94.1	0.5
Average	10,000		320		3.9	93.5	94.4	−0.9

Having so corrected the abundances of the ions, one can calculate the isotopic abundance-ratio from the formula

$$C^{12}/C^{13} = \frac{3x + 2y + z}{y + 2z}$$

where x, y and z represent the abundances of ions of masses 44, 45 and 46, respectively. The abundance-ratio corresponding to each sample is given in Table V and compared to that obtained after combustion. The agreement is good, for the height of the peaks of mass 45 in the mass-spectrum is only about 20% of record width (a third of the peak of mass 45 in CO_2), and errors in estimating background, in recording, and in measurement are therefore larger than in the case of the burned samples.

4. DISTRIBUTION OF THE HEAVY ISOTOPE C^{13} IN PROPANE

By means of the data of Table V, one can compare the actual distribution of the carbon isotopes in propane with a completely random distribution. If the effect of the heavy hydrogen isotope is eliminated, propane molecules of mass 44 contain no C^{13} atoms, those of mass 45

contain one C^{13} atom each, and those of mass 46 contain two C^{13} atoms each. If p is the fraction of all carbon atoms which is C^{13}, and P the fraction of molecules of 3 carbon atoms each in which every molecule contains k atoms of C^{13}, then a random distribution of C^{13} will be represented by the formula

$$P = \frac{3!}{(3-k)!k!} p^k (1-p)^{3-k}.$$

Hence the fraction P_{45} of propane molecules having mass 45 and the fraction P_{46} having mass 46 will be given by

$$P_{45} = 3p(1-p)^2$$

$$P_{46} = 3p^2(1-p).$$

The average abundance-ratio for the propane samples of Table V is $C^{12}/C^{13}=93.5$, so that $p=0.01058$. Hence $P_{45}=0.0310$ and $P_{46}=3.32\times10^{-4}$. If the abundance of mass 44 is represented by 10,000 units, then the abundances of masses 45 and 46 should be 320 and 3.43, respectively. In Table V the corresponding observed averages are 320 and 3.9. The difference of 15% between calculated and observed abundances of the molecule of mass 46 is so much larger than the probable error of the observed value that one must conclude that more C^{13} is present as $C^{12}C_2^{13}H_8$ than would be so combined in a purely random distribution.

5. HYDROCARBONS FROM WELL CUTTINGS

There were available three samples of gaseous hydrocarbons which had been separated from the cuttings of an experimental well drilled on the grounds of the Stanolind Oil & Gas Company Laboratory, and these were burned in the manner previously described. Abundance-ratios calculated from the mass-spectra of the resulting CO_2 are given in Table VI. The order is of increasing depth.

TABLE VI. HYDROCARBONS FROM WELL CUTTINGS

Cutting	C^{12}/C^{13}
A	93.2
B	91.6
C	93.4
Average	92.7

No explanation can be offered for the low value in the case of the second sample. However, there may have been a difference in the

technique of separation, since the first and third samples of hydrocarbon gas were separated from cuttings by one operator and the second by another.

6. VEGETATION

Three dry weeds were obtained from locations in the neighborhood of the laboratory which appeared to be free from contamination by hydrocarbons. In each case a leaf from the weed was crumbled into a metal cup, which was placed just below the platinum filament in the combustion chamber, with part of the leaf touching the filament. When the chamber had been evacuated and filled with pure oxygen, the filament was heated to redness to ignite the leaf. About 95% of the leaf was converted to gaseous form in each case. Condensing the CO_2 with liquid air and separating it from water and unburned oxygen were carried out just as in the combustion of hydrocarbon gases. Abundance-ratios calculated from the mass-spectra of the samples of Co_2 are given in Table VII.

TABLE VII. RELATIVE ABUNDANCE OF CARBON ISOTOPES IN WEEDS

Weed	C^{12}/C^{13}
A	92.7
B	92.5
C	92.7
Average	92.6

7. CARBON DIOXIDE DESORBED FROM SOIL

It was at first intended to measure the relative abundance of the carbon isotopes in the hydrocarbons desorbed from soil, but this proved to be very difficult. Approximately 80% of the condensible gas evolved from each soil sample was carbon dioxide, which it was impossible to separate completely from the small quantity of hydrocarbons that was also present. Hence the usual procedure of combustion could not be carried out, and the quantity of hydrocarbons was too small for direct measurement of isotopic abundance.

However, relative abundance of the carbon isotopes was measured in two samples of carbon dioxide desorbed by heating a glass tube containing the soil. In one soil sample, a sandy loam, desorption was carried out in three stages, (a) heating up to 98°C., (b) heating at 98°C., and (c) heating with a Bunsen burner until no more gas could be evolved. Carbon dioxide was collected separately for these three stages and gave $C^{12}/C^{13}=90.2$, 91.2, and 90.0, respectively, or an average

value of 90.5. For a second soil sample, a clay, only the third stage of heating evolved enough CO_2 for measurement, and this gave $C^{12}/C^{13}=$ 90.1. Both samples of soil were obtained at a depth of 5 feet in the vicinity of Tulsa.

DISCUSSION

The data of Tables III and IV show that relative abundance of the carbon isotopes remains essentially constant for petroleum from many parts of the same field and from fields in widely separated locations. The only apparent exception is the sample from Pottowatomie Co., Oklahoma, and even in this case the difference from the other values is so small that one cannot say surely that it is not an error, although the agreement between the two fractions of this sample is very good.

The hydrocarbons from well cuttings show a slight excess of the heavy carbon isotope C^{13}. Here (as in the case of the CO_2 desorbed from soil) the C^{13} was probably concentrated somewhat by selective adsorption and evaporation.

The three samples of weeds had abundance-ratios about 1.6% lower than the average for petroleum. This difference is apparently real, but it is not large enough to permit the present apparatus to make a sure distinction between petroleum hydrocarbons and those derived from vegetation. To identify the source of soil hydrocarbons, one must reduce the overall error of measurement to less than 0.1% for the combination of combustion and mass-spectrometer analysis, and the attainment of such accuracy is certain to be costly.

It is interesting to note that there are systematic differences between the three existing sets of data. The abundance-ratios of Murphey and Nier[9] are all higher than those of Nier and Gulbranson,[8] which were measured two years earlier, the average difference being 0.9%. (See Table I.) Moreover, our average value for petroleum is 1.7% higher than that of Murphey and Nier, and our value for weeds, 0.9% higher than their value for wood. The results from burned and unburned propane (Table V), suggest that the method of combustion may alter the relative abundance, depending on how diffusion and vaporization operate in the purification of the CO_2. It seems unlikely that differences between mass-spectrometers could have such an effect.

I wish to express my appreciation to the Stanolind Oil and Gas Company for permission to publish this paper.

PREPARATION OF MANUSCRIPTS FOR PUBLICATION IN *GEOPHYSICS*

L. L. NETTLETON*

ABSTRACT

This paper is prepared to aid authors submitting material to GEOPHYSICS so that a larger proportion of the manuscripts, as received by the Editor, may be in suitable form for publication. Particular attention has been given to the preparation of material for illustrations, and diagrams are included which will indicate whether or not a given drawing or map will produce a satisfactory illustration when reduced to the limits of the printed page. While prepared especially for GEOPHYSICS, the same general considerations apply to the preparation of manuscript and illustrations for other technical journals.

From conversations with previous editors of GEOPHYSICS it seems that much difficulty in securing the proper type of manuscript and much correspondence between editor and author may be avoided if the general requirements for acceptable manuscripts are set forth in some detail. This paper, therefore, is prepared largely in the selfish interests of the editor, with the hope that this investment in time and effort may pay substantial dividends to him and later editors in reducing the chores of the editor's job.

Geophysics is still largely a science of young men, and there are many who are relatively new in the field and who may have ideas which they would like to present to their profession. If this material serves to help these younger men who are inexperienced in the preparation of papers for publication and encourages them to submit material to the journal, it will have served a useful purpose. Furthermore, many who have prepared numerous manuscripts may become careless, particularly with regard to the preparation of illustrative material, and it is hoped that the diagrams and instructions in this regard contained herein may be useful in quickly judging the legibility with which their illustrations will appear when published.

GENERAL NATURE OF MATERIAL DESIRED

GEOPHYSICS has the same general standards for acceptance of material for publication as many of the other high-class scientific and technical journals. Its particular field, of course, is underground exploration. This includes all sorts of technical details of new or of pres-

* Gulf Research & Development Company, Editor of GEOPHYSICS, 1945–47.

ently-used exploration procedures, including theory, instruments, interpretation of data, and topics in pure geophysics which might prove useful in the future or may aid in the use of present geophysical or geological methods. In certain cases, general discussions of field procedures under special or unusually difficult conditions are quite acceptable; such papers will be judged on the basis of the service which they may render to other members of the society or profession who might be considering conducting exploration work in similar circumstances. Complete assemblies or case histories of geophysical projects are particularly solicited at the present time, since a project of compiling a volume of such cases is just getting under way. The cases which are most interesting are those where a number of stages or types of geophysical exploration have been carried out, and where the geophysical results have been tested by drilling. GEOPHYSICS also is the official organ of the Society of Exploration Geophysicists and will accept articles or discussions dealing with professional aims and interests of geophysicists.

Material accepted for publication becomes available, without reservation, to the profession. This may raise difficulties in a field as highly competitive as is geophysical prospecting, and it cannot be expected that details of methods or the results of surveys will be published when such publication would involve any risk to the operator who carried out the work. Some material which might not be available otherwise is occasionally submitted by using maps without identifying location or orientation. As a professional journal, GEOPHYSICS is not available for the promotion of new methods or devices, except as this may be done by adequately disclosed technical material. If new exploration methods or procedures are presented, the technical details should be given as completely as security permits. If the development has not reached such a stage (which may be defined in terms of patent protection), and the editor feels that the material is not being presented in a complete enough way to be of service to your profession, he may decline to accept the material submitted.

GENERAL HANDLING OF MANUSCRIPTS

Any manuscript intended for publication in GEOPHYSICS should be sent directly to the editor. It is desirable that the original and one carbon copy be sent, for the second copy is useful in arranging for reading of the manuscript by a referee. Also, it is desirable to include a set of prints of any drawings made on cloth or tracing paper;

these prints can be used as the paper is read by the editor or sent to a referee, thus avoiding risk of loss or damage to the originals. The manuscript will be reviewed by the editor and by one or more anonymous referees, who are specialists in the field concerned. Criticism as to form or manner of presentation of technical material very frequently requires returning the manuscript to the author for correction, deletion, or addition, and, occasionally, for entire rewriting. The receipt of manuscripts will be acknowledged by the editor and the author advised as shortly thereafter as is feasible (usually within two or three months and after review by the referee) as to whether or not the material as submitted is suitable for publication. The original of the manuscript and the illustrative material is ordinarily returned to the author with galley proof. The author will check the galley proof and return it promptly to the editor.

FORM OF MANUSCRIPT

Manuscripts must be typewritten in English only and with double or triple spacing and wide margins to permit the addition of proofreading notes, corrections, etc.

Bibliographic references should be given as footnotes and numbered consecutively. The author's name, title of article, the journal, volume number, page number, and year (or month and year) should be given in the above order. It is desirable to include both the beginning and final page numbers; this serves to indicate the length of the article and is of particular service in connection with ordering photostatic or microfilm copy. The title of the article should be underlined and will be set in italics when printed. For example:

Carl A. Moore. *Preparation of Lantern Slide Copy.*
Bull. A.A.P.G. 26, 1656–1671 (October, 1942).

References to obscure or foreign journals should not be abbreviated so much that they lead to difficulty or ambiguity in identification of the proper publication.

Mathematical expressions should be written in such a way as to minimize the space required and the cost of type setting, as these may vary greatly with equivalent expressions for the same mathematical relation. A fraction requiring two lines of typed space is reduced to one line by the use of the solidus (/). Root signs and reciprocals can be avoided without sacrifice of clarity of expression by using fractional and negative exponents. Only the simplest expressions should be typewritten; all others should be carefully written by hand.

If there is any question of the position of an exponent or a subscript it may be clearly indicated by the use of the caret (∧) over a subscript or (∨) under an exponent. As a rather extreme example, note that the following two expressions are mathematically equivalent, but the upper one requires four lines of type-space and a root sign while the lower requires only one line:

$$U_{zz} = 4\pi\gamma\sigma \frac{R^3}{z^2} \cdot \frac{\dfrac{x}{z}}{\sqrt{\left(\dfrac{x^2}{z^2} + 1\right)^5}}$$

$$U_{zz} = 4\pi\gamma\sigma(R^3/z^2) \cdot [(x/z)(x^2/z^2 + 1)^{-5/2}].$$

ILLUSTRATIONS

The preparation of good copy for illustrations is often one of the most troublesome parts of the preparation of a manuscript. The fact that, when reproduced, the illustration has to fit within the page-size of the magazine must be always kept in mind. The maximum dimension of the figure when reproduced may be a half-page width (approximately two inches), a full-page width ($4\frac{1}{8}''$) or a full-page length ($6\frac{1}{4}''$). The general requirements for the preparation of good illustrative material are much the same as for the preparation of good lantern slide copy, and this subject has been discussed at length by Moore.[1] From the size of the original copy, the amount of reduction required for printing may be determined and the general appearance or legibility of the figure when printed may be estimated in terms of distance at which the original copy is legible. Maps, electric logs, and other such material for which the original is of large size, often contain lettering, printing, or other details which are read easily enough when the material is laid out on a desk, but which may be entirely illegible when reduced to the size required for printing. Fig. 1 is a diagram (modeled after one by Moore) which shows the relation between the greatest distance at which illustrative copy is legible and the maximum dimension of the original drawing for making an illustration which will reach across the page ($4\frac{1}{8}''$ wide) or when used for a full-page illustration ($6\frac{1}{4}''$ wide). An illustration may be tested by holding it up or tacking it on a wall and stepping back to the maximum distance at which it is clearly legible. If the point located by this distance

[1] Carl A. Moore. *Preparation of Lantern Slide Copy.* Bull. A.A.P.G. 26, pp. 1656–1671 (October 1942).

as ordinate, together with the maximum dimension of the original copy as abcissa, falls in the space above the upper line of Fig. 1, the material will make a reasonably satisfactory illustration when reproduced at full-page width. If the point falls between the two lines, it should be reproduced at full-page length. If the point falls below the lower line, a satisfactory reproduction cannot be expected without resorting to a special insert.

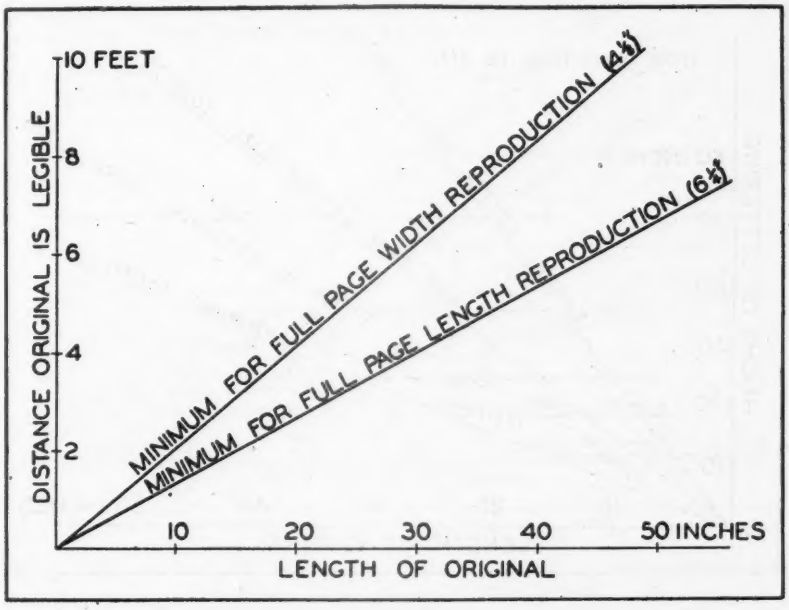


FIG. 1. Relation between size of drawing and legibility for reproduction across a page or full page length in GEOPHYSICS. For points above the lines, a satisfactory reproduction at the corresponding size may be expected. For points below the lines, the corresponding reproduction would be illegible.

Much the same considerations apply to the choice of sizes of lettering, and it is easy to err on the side of having the letters too small. The minimum height of letter which is barely legible is about .015 inches, but a much more comfortable minimum (at least for eyes as old as your editor's) is about .03 inches. Ordinary lower case letters in GEOPHYSICS are about .06 inches high and the capitals are .10 inches high. Fig. 2 shows the relation between the height of lettering an original copy and the height with which it will appear when reduced for reproduction as an illustration reaching across the width of

a page. For convenience, the heights of letters corresponding to the usual Wrico lettering guide sizes are also indicated. For instance, if one had a map or diagram twenty inches wide, which is to be reproduced at a width of $4\frac{1}{8}$", and it is lettered with a 350 Wrico guide, the lettering as reproduced will be slightly larger than the ordinary type in GEOPHYSICS and would be satisfactory. But, if a 140 guide were used,

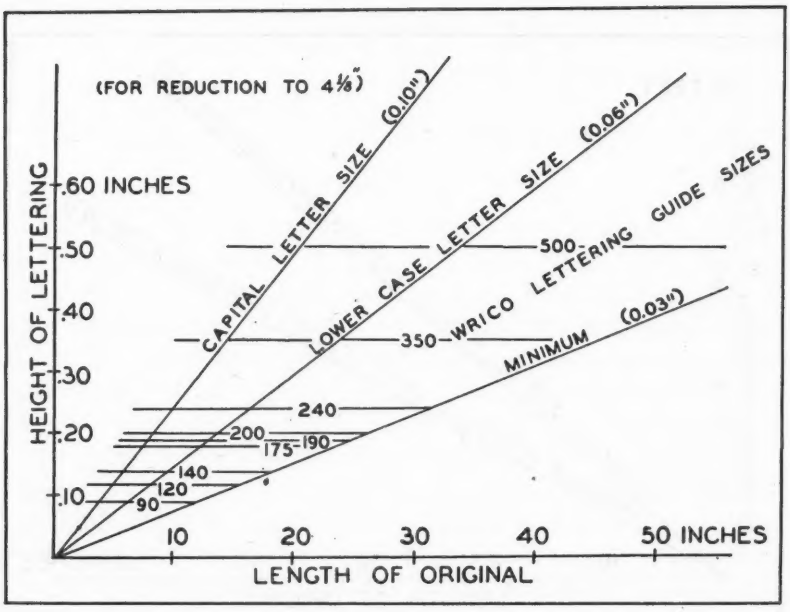


FIG. 2. Relation between size of lettering on original drawing and size it will appear when reduced for printing across a page in GEOPHYSICS. Slanting lines indicate size letters will appear when printed.

the lettering would be under the suggested minimum and would be so small as to be very difficult to read.

Fig. 3 is a similar diagram for copy which is to be reproduced as a full-page illustration.

Maps or other diagrams which are outside the limitations prescribed by Figs. 1, 2, and 3 should first be reconsidered to see if they can be simplified, if the lettering size can be increased, or if they can be otherwise modified so as to come within the limitations for good illustrative material. (A number of instances of simplified re-drafting are given in Moore's article.) If this cannot be accomplished reason-

ably, consideration will be given by the editor to reproduction on special, extra-sized sheets which are printed separately and pasted into the magazine. This, of course, is to be avoided if at all feasible, because of the very considerable item of extra expense involved.

The most common and generally most satisfactory drawings are made with drawing ink on tracing cloth. Drawings on white paper are

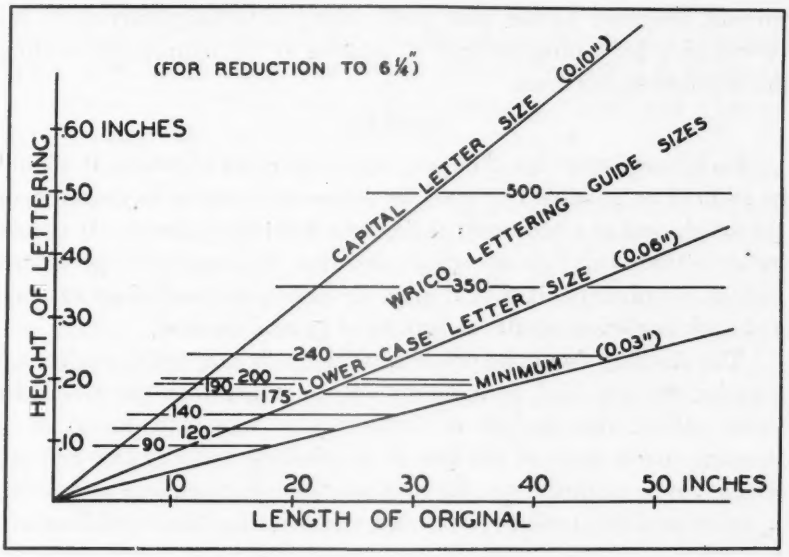


FIG. 3. Same as Fig. 2, but for reproduction as full page illustration. Slanting lines indicate size letters will appear when printed.

satisfactory but have the disadvantage that prints or copies for the author's record or for transmittal with the manuscript are not easily made. When submitting such material as seismograph records or electric logs, their reproducibility should be considered carefully; it may be desirable to trace over with ink or copy those parts which are to be shown. Photographs must have good contrast and must not be too small; and care should be taken that obscure details, which may not show when printed, are not an essential part of the illustration.

Tables of numerical data or other such material should be prepared on sheets separate from the main part of the manuscript. Usually, they will be set up in type and, therefore, the copy may be typewritten and special lettering is not required. Box headings in

tables should be self-explanatory; when they cannot be made short, add an explanatory footnote. Units should be given for each column. It is desirable that a table together with its caption be complete in itself so that its meaning is clear without reference to the text.

Captions for figures and for tables should be given in a separate list. Such captions should be complete enough so that the significance of the figure or table is reasonably clear from the caption alone, and without reference to the text itself. Many a technical article is reviewed only by leafing through it, looking at the figures and reading the captions under them.

ABSTRACT

Each manuscript must be accompanied by an abstract. It should be as brief as possible but must be adequate to serve as an index of the article and as a summary of the principle points therein. It should indicate those subjects on which any new information is presented and, as a summary, it should give the principal conclusions reached and such numerical results as may be of general interest.

The abstract should be prepared with much care and thought as it may be the first (and perhaps the only) contact with the article by those outside the readers of GEOPHYSICS, who will know of it through one or more of the five or six abstract services and journals which cover GEOPHYSICS. If your abstract is adequate and brief, it quite probably will be reprinted verbatim by these publications.

PHOTOGRAPHS AND BIOGRAPHIES

It has been a custom for some years for GEOPHYSICS to publish a photograph and brief biographical sketch of each new contributor to its pages. Fellow professional geophysicists are interested in more than such expression of the author's personality as may be inferred from a bare technical paper. They like to know what he looks like, his educational and professional background and experience and his present situation. Examples of the desired type of material may be seen in the "Contributors" section of any recent number of GEOPHYSICS.

FOREIGN GEOPHYSICAL ACTIVITIES IN 1944–45*

PREPARED BY PETROLEUM ADMINISTRATION FOR WAR

The greatly increased requirements for oil production in foreign countries which have been established in the World Petroleum Supply Programs for 1945 and 1946 cannot be fully met from existing fields and wells. Additional drilling must be accomplished in proven areas to increase productive capacity. Other wells, exploratory in character, must be drilled to discover new fields which, in turn, can be developed to sustain production, meet programmed increases, and establish some reserve capacity to meet unforeseen demands.

The location of suitable areas for exploratory drilling is dependent to a large extent upon the execution of geophysical surveys. Prospectively favorable areas which had been found by pre-war work require further detailing in order that test wells can be located most advantageously. Additional prospects must be found and surveyed because the backlog of such areas is insufficient to sustain an adequate wildcatting program. For all these reasons, it has been necessary to accelerate the program for foreign geophysical exploration in 1945 as compared with earlier years.

During 1942 and 1943 very little work in geophysical exploration was carried on in foreign countries. Chiefly because of shortage of tankers the foreign petroleum industry was dependent almost entirely upon its reserves of productive capacity established in previous years and very little additional development was programmed during those years. Toward the end of 1943 these conditions were altered and, during 1944, a program calling for considerable geophysical exploration was approved.

Detailed reports on the number of geophysical crews in operation during the first half of 1944 were not obtained. Commencing with the third quarter of 1944, 64 geophysical parties were engaged in foreign petroleum exploration. This number was increased to 65 during the fourth quarter. Approximately two-thirds of the investigations were seismic and about one-third gravimetric.

As compared with 1944, the geophysical work programmed for 1945 contemplates a 50 per cent increase in foreign parties. The average of about 65 parties for the last half of 1944 is expected to be increased to an average of about 95 parties for the entire year of 1945.

* Read at the Tulsa, Houston, and Dallas Meetings, 1945.

FOREIGN GEOPHYSICAL OPERATIONS BY AREAS AND METHODS

	Mexico, Central America, West Indies	Caribbean	Other South America	Eastern Hemisphere	Totals
3rd Quarter, 1944					
Seismic	1	28	8	3	40
Gravimetric	2	16	3	1	22
Magnetic	0	2	0	0	2
	3	46	11	4	64
4th Quarter, 1944					
Seismic	3	29	8	3	43
Gravimetric	3	12	3	1	19
Magnetic	0	3	0	0	3
	6	44	11	4	65
3rd–4th Quarters, 1944	6.9%	69.8%	17%	6.1%	
Programmed					
1st Quarter, 1945					
Seismic	5	36	7	3	51
Gravimetric	6	20	1	3	30
Magnetic	2	2	0	1	5
	13	58	8	7	86
2nd Quarter, 1945					
Seismic	6	39	7	2	54
Gravimetric	6	21	1	3	31
Magnetic	3	2	0	1	6
	15	62	8	6	91
3rd Quarter, 1945					
Seismic	9	39	9	4	61
Gravimetric	7	20	3	4	34
Magnetic	3	2	0	1	6
	19	61	12	9	101
4th Quarter, 1945					
Seismic	11	39	9	5	64
Gravimetric	7	20	3	5	35
Magnetic	3	2	0	1	6
	21	61	12	11	105
1945	17.7%	63.2%	10.5%	8.6%	

The same approximate proportion of seismic to gravimetric parties will be maintained. In the accompanying table is shown an analysis, by areas and methods, of all foreign geophysical operations for the last half of 1944 and the programmed operations for 1945.

Foreign geophysical work is overwhelmingly in the Western Hemisphere. In 1944, 94 per cent of the parties were operated in the Western Hemisphere, as compared with 6 per cent in the Eastern Hemisphere. Programmed operations for 1945 called for about 91 per cent of the parties to operate in the Western Hemisphere as against about 9 per cent in the Eastern Hemisphere. About two-thirds of the Western Hemisphere operations are concentrated in the Caribbean area.

DISCUSSIONS AND COMMUNICATIONS

"GEOPHYSICS IN NATIONAL DEFENSE"

AN ESMWT COURSE CONDUCTED AT THE COLORADO SCHOOL OF MINES

In the October 1944 issue of GEOPHYSICS, Mr. M. D. Dobrin gave a report of a course in petroleum geophysics which he very ably conducted in Washington, D. C., under the auspices of the ESMWT and sponsored by George Washington University for fifteen weeks following May 1, 1944.

I should like to call attention to another course on geophysics given under the auspices of the ESMWT but sponsored by the Colorado School of Mines. The course was entitled "Geophysics in National Defense" and was given for a period of twelve weeks beginning January 6, 1942. The lectures and recitations consisted of two 2 hour periods per week plus one 3 hour laboratory period per week. The lectures were given by C. A. Heiland and the laboratory program was carried out by D. Wantland and R. M. Tripp.

There were twenty students enrolled in the course of which about 60% were geologists employed by the Geological Survey, The Bureau of Reclamation, and various oil companies. Of the remaining 40% some had little or no contact with mineral exploration or geophysics in particular before enrollment.

The course was divided into two parts. The first half dealt with the application of geophysical methods to location and detection problems in the air, on land, and at sea. The following subjects were covered: the location of hostile guns by sound and flash ranging; airplane detection by acoustic, optic, and radio means; detection of hostile sappers; submarine detection; harbor surveillance; adjustment of friendly artillery; remote control demolition; marine communication and signaling; radio acoustic position finding; marine echo sounding; and aerial terrain sounding.

The direct application of prospecting geophysics to various war problems was treated in some detail. The methods and results of foundation investigations for heavy gun implacements, fortifications, highways, harbors, and munition plants were discussed. Such topics as geophysical location of ground water, flood control, irrigation, and power projects were considered briefly.

The second part of the course dealt with the possibilities and results obtained by geophysical exploration for strategic minerals. Particular stress was laid on the underlying theory, in order that intelligent reasoning might be carried forward by the enrollees. The minerals receiving major attention were petroleum, coal, aluminum (both bauxite and alunite), antimony, chromium, manganese, mercury, nickel, tin, and tungsten.

Applications of geophysical methods in mining other than for ore location were touched upon, such as investigations of mine caving, rock bursts, drainage, etc.

The laboratory program consisted largely of field problems, designed to emphasize the principles discussed in lectures and to illustrate applications. Experiments consisted of acoustic ranging for enemy artillery (a conventional reflection seismograph was employed for this purpose), seismic refraction investigations for water table and foundation studies, use and operation of magnetometer for mineral investigations, use of resistivity method for locating the water table and studying foundation characteristics and locating construction material, use of the equipotential line method for locating lost

practice weapons and powder magazines, application of the gravity meter to mining exploration, use of the self potential method in prospecting for sulphide ore bodies, and the operation of radio frequency instruments for land mine detection.

Three laboratory periods were devoted to methods for determining the magnetic susceptibility, elastic moduli, and resistivity of rock samples.

The Colorado School of Mines Quarterly, Geophysics in War, by C. A. Heiland served as an outline for the course. A strong emphasis was placed upon the utilization of geophysical techniques and geophysical principles adapted to solve immediate military problems.

R. MAURICE TRIPP

The Geotechnical Corporation
Cambridge, Mass.
Apr. 24, 1945

PATENTS*

ELECTRICAL PROSPECTING

U. S. No. 2,368,217. H. C. Hayes. Iss. 1/30/45. App. 8/2/40.

Electrical Prospecting. An electrical self-potential method of oil prospecting by making a potential difference survey along a line and using features of the plot which are similar to those observed over known oil deposits to determine presence of oil under the survey line.

U. S. No. 2,368,218. H. C. Hayes. Iss. 1/30/45. App. 12/6/44.

Electrical Prospecting. An electrical self-potential method of oil prospecting by making a potential difference survey along a line, correcting for regional potential drop, and using features of the corrected plot which are similar to those observed over known oil deposits to determine presence of oil under the survey line.

GEOCHEMICAL PROSPECTING

U. S. No. 2,366,351. J. L. Patton. Iss. 1/2/45. App. 8/7/40. Assign. Socony-Vacuum Oil Co., Inc.

Measurement of the Rate of Soil Gas Evolution. A method of determining the rate of soil gas emanation by inserting a collecting tube below the water table, sealing off the upper part of the hole with an expansible packer, pumping off water seepage and withdrawing the gas.

U. S. No. 2,367,592. E. McDermott. Iss. 1/16/45. App. 1/22/40.

Method of Prospecting for Buried Deposits. A method of soil analysis prospecting in which soil samples are analyzed for sulphate content or the total water-soluble content.

U. S. No. 2,367,664. J. G. Campbell and R. H. Fash. Iss. 1/23/45. App. 12/31/40. Assign. R. H. Fash.

Method of Petroleum Exploration. A method of soil analysis which eliminates a pre-

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation Patent Department.

liminary drying by adding a small amount of water-miscible oil solvent and extracting with a water-insoluble oil solvent having a water-adhesion energy greater than the water-adhesion energy of petroleum.

U. S. No. 2,370,703. W. M. Zaikowsky. Iss. 3/6/45. App. 8/2/40. Assign. Consolidated Engineering Corp.

System for Gas Analysis. A method and apparatus for soil gas analysis which effects separation of components by low temperature fractionation.

U. S. No. 2,370,793. L. Horvitz. Iss. 3/6/45. App. 3/10/41. Assign. E. E. Rosaire.

Geochemical Prospecting. A method of soil analysis prospecting in which samples are analyzed for each of a group of ionizable inorganic salts.

U. S. No. 2,371,637. E. McDermott. Iss. 3/20/45. App. 1/22/40.

Method of Prospecting for Buried Deposits. A method of soil analysis prospecting in which samples are heated to about 500°C. in presence of oxygen to remove vegetable matter carbon, then further heated to about 600°C. in presence of oxygen to remove further carbon and the latter determined.

GRAVIMETRIC PROSPECTING

U. S. No. 2,367,126. P. H. James. Iss. 1/9/45. App. 12/19/40.

Gravimeter Null Indicator. An underwater gravimeter in which the instrument swings freely from the outer case and having a pointer on the suspended mass to vary light falling on a pair of photocells, and a flexible cable to make the null adjustment.

U. S. No. 2,372,252. D. H. Clewell. Iss. 3/27/45. App. 7/12/40 and 8/14/43. Assign. Socony-Vacuum Oil Co., Inc.

Pivot for Gravity Meters. A pivot or hinge for a horizontal beam gravity meter in which a leaf spring is clamped to the support at its mid-point and the ends fastened to arms of the moving system.

SEISMOGRAPH PROSPECTING

U. S. No. 2,367,049. O. S. Petty. Iss. 1/9/45. App. 2/15/40.

Automatic Volume Control for Recorder Amplifiers. An automatic contractor-expander for seismograph amplifiers in which the output on first arrival actuates a relay which applies increased negative bias to a tube grid and release of the relay permits return to normal bias by a condenser discharging through a resistor.

U. S. No. 2,369,081. E. M. Shook and R. W. Olson. Iss. 2/6/45. App. 3/20/40 and 3/12/43. Assign. Socony-Vacuum Oil Co., Inc.

Apparatus for Transmitting Seismic Signals. A circuit for obtaining both shot moment and up-hole impulses on a regular geophone trace in which these impulses fire thyratrons thereby blocking subsequent interference.

U. S. No. 2,369,082. E. M. Shook and R. W. Olson. Iss. 2/6/45. App. 3/20/40 and 3/12/43. Assign. Socony-Vacuum Oil Co., Inc.

Apparatus for Seismic Surveying. A circuit for transmitting over a voice communi-

cation channel the shot moment and up-hole impulses in which these fire thyratron tubes.

U. S. No. 2,370,483. G. Muffly. Iss. 2/27/45. App. 8/14/42. Assign. Gulf Research & Development Co.

Amplifier. An amplifier having band pass characteristics obtained by using two inverse feedback resistance tuned amplifiers with their inputs in parallel and their outputs in opposition.

U. S. No. 2,371,973. J. P. Minton. Iss. 3/20/45. App. 1/10/44. Assign. Socony-Vacuum Oil Co., Inc.

Geophysical Prospecting Apparatus. A variable air gap reluctance type geophone using an a-c magnetic bridge type of carrier wave modulation.

U. S. No. 2,372,056. R. A. Broding. Iss. 3/20/45. App. 6/21/41. Assign. Socony-Vacuum Oil Co., Inc.

Method and Apparatus for Recording Seismic Waves. A balanced carrier current type of geophone having three fixed coils, the middle one providing inductive excitation to the outer ones which are tuned off resonance and carry a suspended armature whose displacement causes one circuit to approach resonance and the other to depart further from resonance.

WELL LOGGING AND SURVEYING

U. S. No. 2,366,694. J. C. Bender. Iss. 1/9/45. App. 11/21/41. Assign. McCullough Tool Co.

Means and Method of Well Logging. A method of thermal logging of a cased well by measuring the electrical conductivity of a thermally conditioned fluid in the well, correction being automatically made for the normal temperature gradient.

U. S. No. 2,366,826. H. Allen. Iss. 1/9/45. App. 12/26/40. Assign. Cameron Iron Works, Inc.

Bottom Hole Pressure Recorder. A recording bottom hole pressure gauge whose elastic system is a narrow M-shaped bar, force being applied to the center junction which spreads the other two junctions to operate the pen through a linkage.

U. S. No. 2,368,413. T. A. Creighton. Iss. 1/30/45. App. 6/14/41.

Apparatus for Orienting Well Tools. A device for checking the orientation of a whipstock which takes one orientation record in the drill stem and another with the surveying instrument deflected in a known relation to the whipstock.

U. S. No. 2,368,486. J. J. Mullane. Iss. 1/30/45. App. 2/2/42. Assign. Standard Oil Development Co.

Well Logging. A method of radioactivity mud logging in which a proportional Geiger counter is exposed to the mud return and alpha particle activity recorded.

U. S. No. 2,368,532. R. E. Fearon. Iss. 1/30/45. App. 12/27/39. Assign. Well Surveys, Inc.

Well Survey Method and Apparatus. A method of radioactivity logging over a single

conductor cable in which a-c power and d-c for balancing the ionization gauge circuit is sent down the cable, and the unbalance is signalled up the cable on a carrier frequency and used to indicate and control the balancing d-c.

U. S. No. 2,369,403. G. E. Nevill. Iss. 2/13/45. App. 3/18/35 and 10/30/42. Assign. J. V. Robinson.

Means and Method of Surveying Wells. A method and apparatus of well surveying in which the survey instrument is carried in an extension on the front of a dummy wire line core barrel so as to get away from magnetic drill stem interference.

U. S. No. 2,369,550. A. Frosch. Iss. 2/13/45. App. 6/30/41. Assign. Standard Oil Development Co.

Well Logging. A method of gamma ray well logging using a single conductor cable both for feeding power down the cable at one frequency and transmitting instrument indications consisting of thyratron impulses whose frequency is a measure of the gamma ray activity.

U. S. No. 2,369,672. D. G. C. Hare. Iss. 2/20/45. App. 10/21/41. Assign. The Texas Company.

Method and Apparatus for Logging Boreholes. A method and device for radioactivy logging in which the instrument is shielded from one side of the hole and urged against the other side of the hole by a spring arm which also gives a caliper log of the hole.

U. S. No. 2,369,811. R. W. Stuart. Iss. 2/20/45. App. 7/3/41. Assign. Stanolind Oil & Gas Co.

Drill Mud Logging Recording System or the Like. An apparatus for indicating wide ranges of gas concentration in drilling mud logging by the use of a recording amplifier having logarithmic response attained through grid rectification.

U. S. No. 2,370,162. D. G. C. Hare. Iss. 2/27/45. App. 10/16/41. Assign. The Texas Company.

Method and Apparatus for Logging Boreholes. A method of radioactivity logging using a number of detectors each modulating a carrier wave of different frequency and on the surface separating and recording the signals.

U. S. No. 2,370,814. J. A. Riise, Jr. Iss. 3/6/45. App. 6/26/41. Assign. Phillips Petroleum Co.

Method of Well Logging. A method of electrical well logging in which fresh water is introduced into the hole until it counterbalances formation pressure and repeated logs made with increasing pressure.

U. S. No. 2,370,818. D. Silverman. Iss. 3/6/45. App. 7/30/42. Assign. Stanolind Oil and Gas Co.

Well Measurement. A method of well logging while drilling in which the frequency of a self contained oscillator at the bottom changes with the quantity logged, and the signal is picked up with an electric coupling unit lowered through the drill stem and recording at the surface.

U. S. No. 2,371,270. A. L. Smith. Iss. 3/13/45. App. 7/29/40.

Electrical Logging of Well Bores. A method of electrical logging in which current is passed through a long bare resistor lowered in the well and variations in the apparent resistance recorded.

U. S. No. 2,371,628. S. Krasnow. Iss. 3/20/45. App. 12/31/40.

Method and Apparatus for Dynamic Measurement of Borehole Radioactivity. A method of radioactivity logging in which the time rate of change of ionization chamber current is recorded by having a large inductance in series with the ionization chamber and in which the speed of motion of the device in the well is also recorded.

U. S. No. 2,372,576. J. T. Hayward. Iss. 3/27/45. App. 4/20/42.

Method of Determining Formation Porosity During Drilling. Determining formation porosity by observing the drilling rates under uniform drilling conditions of the cap rock and of the underlying porous formation, and comparing the ratio of these drilling rates with that of known formations.

U. S. No. 2,372,582. C. H. Kean. Iss. 3/27/45. App. 11/2/40. Assign. Standard Oil Development Co.

Means of Transmitting Information. Apparatus for well logging in which the signal is impressed as a vibration on the supporting cable or the well fluid by a magnetostriction or piezoelectric vibrator and similarly picked-up and recorded at the surface.

MISCELLANEOUS

U. S. Re. 22,589 (Orig. No. 2,334,843). A. C. Ruge. Iss. 1/9/45. App. 9/16/39, 8/4/42 and 10/4/44.

Strain Gauge with Thermal Current Control. A filament type strain gauge having small diameter leads from the main current leads to the gauge wire and cemented to the test body so as to dissipate conducted heat and avoid thermoelectric emfs.

U. S. No. 2,366,342. B. J. Lazan. Iss. 1/2/45. App. 4/25/42.

Materials Testing Apparatus. A mechanical oscillator for dynamic vibration testing in which an electric motor revolves a planetary gear of half the diameter and running inside of a stationary ring gear, the oscillating mass being mounted on the circumference of the planetary gear so as to execute linear harmonic motion.

U. S. No. 2,366,897. A. O. Grooms. Iss. 1/9/45. App. 9/2/42. Assign. General Motors Corp.

Atmospheric Pressure Responsive Measuring Device. An aneroid barometer in which a spring on a toggle linkage produces a decreasing opposing force with expansion of the diaphragm.

U. S. No. 2,366,982. R. C. Pryor. Iss. 1/9/45. App. 8/30/43. Assign. Phillips Petroleum Co.

Instrument Release. A releasing head for lowering instruments or tools to the bottom of a well and having a sliding plunger which after the instrument hits bottom continues to fall and releases the jaws holding the instrument.

U. S. No. 2,367,034. I. E. McCabe. Iss. 1/9/45. App. 6/24/42.

Aneroid Barometer. An aneroid barometer in which proper temperature compensation is attained at all pressures by means of a floating pivot controlled by a bimetallic strip.

U. S. No. 2,367,211. M. A. Greenfield. Iss. 1/16/45. App. 3/31/43.

Pressure Gauge. A small wire filament type explosion pressure gauge in which the strain sensitive filament is totally enclosed in glass, connections being made to a central lead and concentric sleeve.

U. S. No. 2,367,561. G. Bouyoucos. Iss. 1/16/45. App. 4/10/43. Assign. Michigan State Board of Agriculture.

Electric Hygrometer. A resistor which varies with humidity and having leads imbedded in a semiconducting mixture of plaster of Paris and glycerine.

U. S. No. 2,368,119. L. J. DeLanty and W. A. Williams. Iss. 1/30/45. App. 11/5/40. Assign. Sperry Products, Inc.

Flaw Detecting Means. An apparatus for detecting flaws in long metallic members by passing a longitudinal current through the member and measuring the potential drop between staggered sets of electrodes.

U. S. No. 2,368,609. E. Burkhardt. Iss. 1/30/45. App. 4/20/40 and 6/7/41. Assign. General Electric Co.

Electroacoustic Transducer. A multicrystal piezo-electric electro-mechanical conversion device having a layer of elastic material between pairs of crystals in order to reduce the mechanical natural frequency.

U. S. No. 2,368,831. C. M. Hathaway. Iss. 2/6/45. App. 9/19/42.

Oscillograph Galvanometer. A bifilar oil immersed oscillograph galvanometer having a permanent magnet with pole pieces in the cell box and also having an oil expansion diaphragm.

U. S. No. 2,369,284. C. R. Dale. Iss. 2/13/45. App. 2/18/44. Assign. 13¾% to J. R. Pemberton and 45% to Technical Oil Tool Corp., Ltd.

Record Reproducing Device. An apparatus for copying in enlarged form the record from a well recording instrument and in which the original record is projected on a translucent screen and traced on a sheet moved synchronously with the record.

U. S. No. 2,369,499. M. A. Treuhaft. Iss. 2/13/45. App. 12/5/40. Assign. J. C. Batchelor.

Apparatus for Measuring Rate of Change. Apparatus in which a quantity whose rate is to be measured influences two electrolytic cells arranged with different time delays and the electrical difference between the cells indicated.

U. S. No. 2,369,788. D. G. C. Luck. Iss. 2/20/45. App. 5/30/42. Assign. Radio Corp. of America.

Rate of Climb Indicator. A rate-of-climb indicator for aircraft in which atmospheric

pressure is applied to a stack of piezoelectric plates having a resistance load and the d-c voltage produced by a changing pressure is balanced by an auxiliary source of d-c which is indicated.

U. S. No. 2,369,802. G. V. Rylsky. Iss. 2/20/45. App. 9/3/42. Assign. Bendix Aviation Corp.

Liquid Level. A bubble type liquid level having a separate air chamber and passages arranged so that the bubble may be removed by tilting and reformed by a finger operated bellows pump.

U. S. No. 2,370,133. S. J. Begun. Iss. 2/27/45. App. 4/2/42. Assign. The Brush Development Co.

Means for and Method of Timing. An interval timer in which a standard oscillator records only during the interval so that the cycles may subsequently be counted from the record.

U. S. No. 2,370,134. S. J. Begun. Iss. 2/27/45. App. 8/21/42. Assign. The Brush Development Co.

Timing Device. Apparatus for interval timing on a short record and in which an oscillator is automatically alternately recorded and the record obliterated, the number of these processes and the remainder being indicated.

U. S. No. 2,370,163. D. G. C. Hare. Iss. 2/27/45. App. 10/16/41. Assign. The Texas Co.

Method and Apparatus for Examining Opaque Material. A method of testing material for flaws by scanning the material with penetrating radiation, detecting the transmitted intensity, and synchronously photographically indicating or marking this intensity on a recording sheet.

U. S. No. 2,370,176. O. Kornei. Iss. 2/27/45. App. 6/22/42. Assign. The Brush Development Co.

Means for and Method of Measuring Time Intervals. An interval timer in which a signal is recorded on a constant speed disk and subsequently picked up so that the beginning and end of the signal will flash lamps illuminating a scale on the disk.

U. S. No. 2,370,631. C. E. Berry. Iss. 3/6/45. App. 8/19/43. Assign. Consolidated Engineering Corp.

Mass Spectrometry. A device for indicating by means of a balancing and stepping network the ion mass on the record of a mass spectrometer having automatic ion beam sweep.

U. S. No. 2,370,673. R. V. Langmuir. Iss. 3/6/45. App. 9/11/39. Assign. Consolidated Engineering Corp.

Mass Spectrometry. A mass spectrometer in which high recording speed is attained by using a pulsating electron stream to ionize the gas, and passing the resulting modulated ion current signal through a narrow band pass filter.

U. S. No. 2,370,845. H. Davis. Iss. 3/6/45. App. 2/18/42.

Measurement of Stress. A method of measuring stress in ferro-magnetic members by

subjecting a surface to a-c magnetization in different azimuths and observing the magnetic anisotropy and the amount of change produced by an increase in flux.

U. S. No. 2,371,176. P. L. Kirk and R. Q. Boyer. Iss. 3/13/45. App. 2/24/41. Assign. Ventura Tool Co.

Means for and Method of Detecting Flaws in Pipes and the Like. A method of pipe inspection in which a large d-c current is passed through the pipe and a longitudinal cathode ray tube inserted on a telescope, flaws being detected by observing deviation of the cathode ray spot caused by magnetic irregularities.

U. S. No. 2,371,508. H. W. Dietert. Iss. 3/13/45. App. 12/13/43.

Apparatus for Testing the Gas Permeability of Molded Specimens. A device for testing the gas permeability of molding sand by forcing air into the centre of a cylindrical sample and measuring the volume of air supplied.

U. S. No. 2,371,658. W. H. Stewart. Iss. 3/20/45. App. 3/27/41. Assign. Sun Oil Co.

Method and Apparatus for Determining Current Flow in Borehole Casing or the Like. A method of measuring corrosion currents in casing by lowering four contacts into the casing and passing a d-c between the outer contacts such that the potential difference between the inner contacts is zero.

U. S. No. 2,372,091. E. H. Land. Iss. 3/20/45. App. 8/14/42. Assign. Polaroid Corp.

Device for Measuring Vertical Angular Deviation. An inclinometer in which the image of a scale on a pendulum is superimposed on the image of an object observed so as to indicate the inclination of the line of sight.

U. S. No. 2,372,575. J. T. Hayward. Iss. 3/27/45. App. 10/10/38.

Method of Freeing Pipe Jammed in a Well. A method of controlling the deposition of solid matter on objects immersed in suspensions by connecting the object to the negative terminal of a d-c source to set up a field which drives the suspended particles away by electrophoresis.

PUBLICATIONS RECEIVED

(The publications listed below were received since issuance of GEOPHYSICS for April, 1945, and are available for loan to the memberhsip. Articles cited are those of particular interest to geophysicists.)

American Journal of Science, Vol. 243, Nos, 3, 4 (March, April, 1945), New Haven.

Bulletin of the American Association of Petroleum Geologists, Vol. 29, Nos. 1–6 (January–June, 1945), Tulsa. "Geophysical History of South Houston Salt Dome and Oil Field, Harris County, Texas," by J. Brian Eby (February). Review of Exploration and Development in 1944, by numerous authors (June).

Economic Geology, Vol. XXXIX, Nos. 7, 8 (November, December, 1944), Vol. XL, No. 1 (January–February, 1945), Lancaster.

Independent Petroleum Association of America Monthly, The, Vol. XV, Nos. 11, 12 (March, April, 1945), Tulsa.

Journal of Applied Physics, Vol. 16, Nos. 2, 3, 4 (February, March, April, 1945), Lancaster.

Journal of the Institute of Petroleum. Vol. 31, Nos. 253–5 (January–March, 1945), London.

Petroleum, Vol. VIII, Nos. 3, 4 (March, April, 1945), London.

Publicaciones del Instituto de Fisiografia y Geologia:

XXIII. *Paleontologia Estratigrafica de los Sedimentos Neogenos de la Provincia de Cordoba*, by Alfredo Castellanos. Rosario, Argentina, 1944.

Review of Scientific Instruments, The, Vol. 16, Nos. 2, 3 (February, March, 1945), Lancaster.

Revista de Ciencias, Vol. XLVI, No. 450 (December, 1944), Lima, Peru.

Terrestrial Magnetism and Atmospheric Electricity, Vol. 50, No. 1, (March, 1945), Baltimore. "Analysis and Interpretation of Geomagnetic Anomalies," by E. H. Vestine and N. Davids.

World Petroleum, Vol. 16, Nos. 3, 4, 5 (March, April, May, 1945), New York.

CONTRIBUTORS

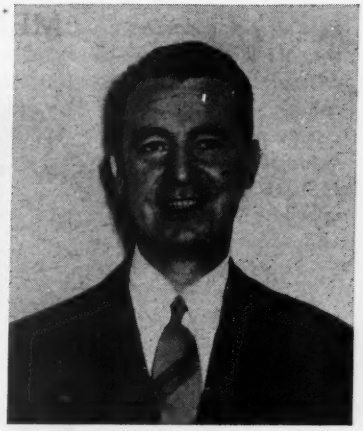
Victor J. Blum, S.J., received his A.B. degree from Xavier University, and his M.A., M.S. and Ph.D. degrees from Saint Louis University. At present he is Assistant Dean of the Institute of Geophysical Technology and Instructor in Geophysics in Saint Louis University. He is a member of the Saint Louis Academy of Science, the Seismological Society of America, the American Physical Society, the American Meteorological Society, the American Geophysical Union, Sigma Xi and the Society of Exploration Geophysicists.

VICTOR J. BLUM, S.J.

Laurence G. Cowles received the degree of B.S. in E.E. from the University of Vermont in 1929 and M.A. in Physics from Columbia in 1932. From 1929 to 1932 he was employed in The Transmission Research Group at the Bell Telephone Laboratories. Since 1934 Mr. Cowels has been engaged in development work in the Geophysical Laboratory of The Texas Company, Houston. He is a member of the American Institute of Electrical Engineers and the Society of Exploration Geophysicists.

LAURENCE G. COWLES

Albert F. Dugan received the degree of B.E. in Civil Engineering from Tulane University in 1936. From 1936–1938 he was engaged in torsion balance exploration, and from 1938 to the present he has been engaged in gravimeter exploration, all of which was for the Magnolia Petroleum Company. He is a member of the American Society of Civil Engineers and is applying for membership in the Society of Exploration Geophysicists.



ALBERT F. DUGAN

Jack W. Peters received the degree of Geological Engineer in Geophysics from the Colorado School of Mines in 1938. Since 1938 he has been engaged in gravity exploration for the Magnolia Petroleum Company. He is a member of the Society of Exploration Geophysicists, the Dallas Petroleum Geologists, Tau Beta Pi and Sigma Gamma Epsilon.

JACK W. PETERS

Photographs and biographies of contributors to this issue not appearing above have been published previously, as follows: W. M. RUST, JR., Vol. VIII, No. 3, p. 319 (July, 1943), B. B. WEATHERBY, Vol. VIII, No. 3, p. 317, (July, 1943), S. S. WEST, Vol. VIII, No. 2, p. 187, (April, 1943), E. D. ALCOCK, Vol. VII, No. 4, p. 426, (October, 1942), L. L. NETTLETON, Vol. VI, No. 3, p. 303, (July, 1941).

MEMORIAL

BILLY E. RICHARDS

First Lieutenant Billy E. Richards, 27, of the U. S. Army Air Corps, met his death August 23, 1944, while on active duty over New Guinea. Lt. Richards had been a student, and then an associate, member of the Society since July, 1941.

Billy was the son of Mrs. Cora M. Richards of Woodston, Kansas, and attended the public schools there. He subsequently received his degree as a geophysical engineer from the Colorado School of Mines. Following his graduation, he accepted a position with the United Geophysical Company, remaining with the company until March, 1942, when he enlisted in the Air Corps. He was commissioned in July, 1943, at Eagle Pass, Texas, and went overseas in December. Prior to his death, he had participated in 86 missions, accumulating 210 hours of combat flying.

I first made Billy's acquaintance during the winter of 1940–41, when he joined my seismograph crew as computer. From the very beginning, he showed the same unselfish and unfaltering fine character which was portrayed by his untimely death in the Jap-infested jungle. He was not required to attack the Jap position on the fatal mission, nor was he thinking of himself when he dived his bullet-riddled P-47 fighter plane into the Jap machine-guns. He had learned the position of the machine-gun nests, and he voluntarily wished to destroy them in order to protect his fellow flyers who would be

sent on missions over the area. With his escort plane doomed and soon to crash, he drove it straight at the Japanese machine-gun nests, with his own machine-guns blasting staccato defiance until the very last. He was willing to sacrifice his own life in order that a few more fellow flyers might live. There is no greater deed to humanity than this.

In his work, as on the last flight over New Guinea, he was ever giving his companions care and protection. Billy was the sort of boy one immediately becomes attached to, and his friendship was highly respect by all his co-workers. He was a brilliant student, and he attacked the daily routine problems with excellent systematic logic. He was careful, accurate in his work, and could adapt himself to almost any combination of circumstances. If anything ever bothered Billy, there never was an outward expression of it. He never complained about the war and its hardships. His only remark was that the greatest hardship was in being away from his wife and home.

He lived with his Mother from the time of his Father's death until his marriage, and the kindness and tender feeling that only a mother can impart was an attribute. The loss of such a person is, indeed, great to his friends, to society at large, and to the profession he had chosen for his life's work.

CECIL E. REEL
Bakersfield, California

THE SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the Secretary within thirty days. (Names of sponsors are placed beneath the name of each nominee.)

ACTIVE

Harry Hugh Andrews
G. H. Westby, A. J. Barthelmes, H. M. Thralls

Keith Raymond Beeman
H. H. Happel, F. F. Reynolds, John D. Marr

Albert Washington Bunsen
A. L. Smith, H. M. Falkenhagen, R. S. Jackson

Lewis Calvin Crider
Neal J. Smith, James H. Todd, Booth B. Strange

Paul Otha Fink
E. A. Eckhardt, L. L. Nettleton, James Affleck

Frank Karr Fisk
E. V. McCollum, L. W. MacNaughton, H. C. Cortes

Siegfried William Fruehling
R. W. Mossman, A. J. Barthelmes, H. M. Thralls

Robert John Gill
Neal J. Smith, James H. Todd, Booth B. Strange

Constant Godefroy
E. G. Leonardon, F. Julius Fohs, J. C. Sproule, L. W. Blau

Gordon Billett Hanchey
James H. Todd, Neal J. Smith, Booth B. Strange

Ross Henderson
Cecil H. Green, Martin C. Kelsey, Earl Thomas

William Leftwich Homan
P. E. Narvarte, C. D. Whitsitt, J. W. Barbisch

Ervand George Kogbetliantz
Bela Hubbard, Dodd Covell Skeels, Joseph A. Sharpe

Vivian Robert Kerr
R. M. Bradley, W. Harlan Taylor, R. L. Kidd

J. C. Legrand
E. G. Leonardon, J. Brian Eby, Charles B. Aiken

Harold Duane Marshall
Craig Ferris, E. V. McCollum, J. G. Ferguson

Holland C. McCarver
J. C. Karcher, Cecil H. Green, H. B. Peacock

Joseph Walter Northrop, III
Leonard Irving Brown, James H. Todd, Neal J. Smith

William Erwin Notley
R. Clare Coffin, Garvin L. Taylor, J. R. Johnson
Richard Henry Parker
H. H. Happel, F. F. Reynolds, John D. Marr
William Ralph Peery
A. J. Barthelmes, H. M. Thralls, Lou G. Cornish
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Hilmi Fahrettin Sagoci
John A. Gillin, W. B. Hogg, E. D. Alcock
Leonard Frederick Schombel
Arne Junger, Joseph C. Waterman, H. R. Thornburgh
Frank Benjamin Smith
W. Harlan Taylor, L. O. Seaman, Homer C. Moore
Banis James Sorrells
W. B. Hogg, Leslie C. Spencer, E. D. Alcock
O. A. Strange
James H. Todd, Henry Salvatori, Neal J. Smith
Alfred Winterhalter
John W. Millington, H. W. Rose, W. E. Hollingsworth
James Eben Woodburn
Albert J. Barthelmes, J. L. Kezeler, Stanley W. Wilcox

ASSOCIATE

Ruth Breedlove
Howard L. Cobb, C. H. Hightower, A. E. McKay
John Paul Jones
J. F. Evans, A. C. Reid, Harold M. Lang
Elliston Bower Lindsey
C. L. Caster, John E. Taylor, Ashton Crain
Jack Lynch
W. H. Morgan, H. E. Banta, Joseph L. Adler
Francis Hoyle Noble
Roy L. Lay, C. R. Wallace, Alfred J. Hibbler
Benjamin Franklin Owings, Jr.
E. D. Alcock, W. B. Hogg, C. J. Lomax
Lewis V. Roos
L. A. Scholl, Jr., Roy L. Lay, C. R. Wallace

STUDENT

Fred Alvin Bender
W. T. Szymanowski

THE FIFTEENTH ANNUAL MEETING OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS

The 1945 meetings of the Society of Exploration Geophysicists were quite different from those of previous years. Originally scheduled to be held as usual, in conjunction with the American Association of Petroleum Geologists on March 21–23, plans were changed when that meeting was cancelled in line with transportation restrictions. The officers of the society felt that the importance of oil exploration was such that special efforts to bring new developments and discussions before the members of the association were justified. Therefore, it was decided to hold several local meetings, each attended by local geologists and geophysicists, by certain officers of the society and, as far as possible, by the authors of the papers presented. In this way, the out-of-town visitors at any meeting would be substantially less than the maximum of fifty, thereby meeting the spirit as well as the letter of the O.D.T. restrictions. Accordingly, meetings were held in Tulsa on April 4, in Houston on April 20, and in Dallas on May 3. The result has been quite satisfactory, with a total attendance of over five hundred; thus, the members of the society who could hear and discuss papers were at least as great as for a normal convention year.

The Tulsa meeting was designated as the official meeting for the year, and the annual official business of the society was transacted at that meeting.

The thanks of the society for the success of these meetings are due to the following committees who made the arrangements:

General Chairman Program and Arrangements Committee

Henry C. Cortes, Vice-President (Now President) of the Society

Areal Committees

(To secure technical papers)

Houston

R. S. Jackson, Chairman
Carryl S. Hughes
Albert L. Ladner
Roy L. Lay
J. C. Pollard
W. J. Osterhoudt

San Antonio

P. E. Narvarte, Chairman
John F. Imle
Frederick E. Romberg

Pacific Coast

O. C. Lester, Jr., Chairman
H. R. Thornburgh
Phil P. Gaby

Dallas

Cecil H. Green, Chairman
E. D. Alcock
W. W. Newton

Pittsburgh

L. L. Nettleton, Chairman
Milton B. Dobrin
James M. Kendall

Ft. Worth-Colorado

John H. Wilson, Chairman
James L. Morris

New York-New England

R. F. Weichert, Jr., Chairman

Tulsa Local Committee

Program

L. Y. Faust, Chairman
R. Clare Coffin, Vice-Chairman
P. S. Williams
Albert J. Barthelmes
Joseph A. Sharpe, Advisory Member

Arrangements

T. A. Manhart, Chairman
George E. Wagoner, Vice-Chairman
A. I. Innes
Homer C. Moore
Stanley W. Wilcox

Dallas-Fort Worth Local Committee

Chairman— Cecil H. Green
Program— John H. Wilson
A. E. McKay
E. D. Alcock
Publicity— W. N. Newton
James L. Morris
Arrangements—M. D. McCarty
Frank H. Kennedy, Jr.
Advisory— Henry C. Cortes

Houston Local Committee

Chairman—R. S. Jackson
Darryl S. Hughes
Albert L. Ladner
Roy L. Lay
W. J. Osterhoudt
J. C. Pollard

The morning and afternoon sessions at the Mayo Hotel in Tulsa were presided over by W. M. Rust, A. B. Bryan, and Henry C. Cortes. The Houston morning and afternoon sessions at the Rice Hotel were conducted by W. M. Rust, Henry C. Cortes, L. W. Blau, Frank Goldstone, and E. E. Rosaire. The Dallas sessions at the Auditorium of the Dallas Power and Light Building were presided over by J. C. Karcher and Eugene McDermott. At Houston and Dallas, there were evening meetings at which families and friends gathered to enjoy two sound color movies, "Deep Horizons," Courtesy of The Texas Company, and "Oil for Tomorrow," Courtesy of the Interstate Oil Compact Commission.

PAPERS PRESENTED OR READ BY TITLE AT THE TECHNICAL SESSIONS OF THE FIFTEENTH ANNUAL MEETING

1. Presidential Address—Evaluation of New Geophysical Methods.
W. M. Rust, Jr., Humble Oil and Refining Company, Houston, Texas.
(Read by Dr. Rust at Tulsa)

2. Geophysical Exploration in Foreign Countries.
Office of Petroleum Administration for War.
(Read by Joseph A. Sharpe in Tulsa, by C. R. Wallace in Houston, and by Lewis W. MacNaughton in Dallas)

3. Early Seismic Discoveries in Oklahoma.
B. B. Weatherby, Geophysical Research Corporation, Tulsa, Oklahoma.
(Read by Dr. Weatherby in Tulsa, by W. T. Born in Dallas)

Systematic seismic reflection shooting was begun on the Seminole Plateau of Oklahoma in 1927. In the beginning the results were somewhat undependable and well checks were disappointing. The various difficulties were gradually ironed out so that with the discovery of South Earlsboro in 1929 and the North Extension of Carr City and West Seminole in 1930, new impetus was given to the use of the

method. The history of these discoveries together with maps and records show the measure of success obtained at that time.

Data on the Polo Field, discovered in 1931 and detailed in 1934, are compared with this early work.

4. Seismograph Evidence on the Depth of the Salt in Southeast Texas.

H. Wayne Hoylman, Gulf Research & Development Company, Pittsburgh, Pa.

(Read in L. L. Nettleton in Tulsa, by W. J. Osterhoudt in Houston, by D. A. DeWoody in Dallas)

Reflection seismograph records shot over the top of the shallow Moss Bluff Salt Dome, Chambers County, Texas, show bands of energy which can be reasonably identified as reflections from the base of the salt. Depth calculations place the bottom of the salt mass at approximately 16,000 feet. Later events on the records are either reflections from the basement complex or multiple reflections. Assuming they are from the basement, the depth is calculated as approximately 25,000 feet. Alternatively, the time relations can be fitted closely in terms of multiple reflections between the base of the salt and the interface at the contact of the cap rock with the overlying sediments where the velocity discontinuity is a maximum.

5. The Attenuation Constant of Earth Materials, II.

W. T. Born, Geophysical Research Corporation, Tulsa, Oklahoma.

(Read by Dr. Born in Tulsa, Houston, and Dallas)

Measurements of the internal friction in a number of rod specimens of consolidated rocks were made by a dynamic method previously described. The losses in water-free specimens were found to be substantially independent of frequency while rocks containing moisture showed, in addition, losses increasing with frequency. The logarithmic decrement of dry rocks ranged from a value of 0.005 for a specimen of Italian marble to values approximately 0.05 for sandstone specimens.

6. Effect of Surface Topography on Seismic Mapping.

M. B. Widess, Stanolind Oil & Gas Company, Tulsa, Oklahoma.

(Read by Dr. Widess in Tulsa and Houston)

The presence of rough surface topography in a prospect frequently constitutes a source of error in seismic mapping and poses the question of what computational methods can be applied by which seismic maps might be freed of the effect of surface relief. Various aspects of the problem are described. The use of a plane datum horizon is generally adequate as a solution of the problem. The datum horizon may be modified to account for the over-burden effect, the approximate magnitude of which is considered. Further modification may be required by lateral variations in subweathering velocity. Statistical analysis for determining the degree of conformity between surface topography and mapped structure at depth is a useful tool in the study.

7. Refraction Waves Reflected at a Fault zone.

W. B. Robinson, Gulf Research & Development Company, Pittsburgh, Pa.

(Read by Mr. Robinson in Tulsa, by John E. McGee in Houston, by Martin C. Kelsey in Dallas)

Many records of a reflection project in Webb County, Texas, displayed events showing excessive stepout times. These events are treated as refraction waves following a near-surface marker horizon, and their origin is shown to be associated with faulting which was mapped by the ordinary reflections on the records. A similar discussion was presented by Deacon.[1] Possible confusion that may arise from failing to recognize these anomalous events is discussed as well as the possibility of using the phenomenon to map faults.

[1] L. E. Deacon, GEOPHYSICS, Vol. VIII, No. 1 (Jan. 1943) pp. 3–8.

8. Airplane-Noise Interference with Seismic Prospecting.

J. M. Kendall, Naval Ordnance Laboratory, Washington, D. C.
(Read by Dr. Kendall in Tulsa, by H. E. Banta in Houston)

The sound fields produced by airplanes are briefly investigated. Rough calculations are made to determine the response of geophones to this sound field. Measures suggested for minimizing interference are discussed.

9. Gravimetric and Magnetic Surveys in the Gas Fields of Southwestern Ontario, 1941 and 1942.

A. A. Brant, University of Toronto.
(Read by R. D. Wyckoff in Tulsa)

During 1941 gravitymeter measurements previously made in southwestern Ontario were compiled and checked, while in 1941 and 1942 a vertical magnetometer survey of this part of the province was carried out.

Measurements of the density and magnetic susceptibility of drill hole samples down to the basement, and calculation on the basis of these results of the anomalies associated with known structures, as well as the mathematical solution of the depths of the anomalies, indicated that the major portion of both the gravity and magnetic anomalies encountered were due to conditions in the basement.

On the basis of the anomalies observed, basement lines of weakness were postulated and from structural studies inferences were made as to how these weaknesses might react and produce gas bearing structures under the succession of forces that gave rise to the Appalachian Basin, Cincinnati Arch, etc.

10. A Department for Review and Analysis of Seismic Data.

E. D. Alcock, National Geophysical Company, Dallas, Texas.
(Read by Mr. Alcock in Tulsa and Dallas)

It is proposed that separate departments be established for the review and analysis of seismic data. The functions of these departments would be to review and submit independent interpretation of current seismic data, to review old seismic data in the light of new geological and geophysical developments, to compile and prepare regional seismic maps and to investigate areas in which seismic and geological data do not conform. This paper discusses the benefits to be expected from such a program, the source of man power, and the costs.

11. Gravimeter Operations in the Foothills Belt of Alberta, Canada.

W. K. Hastings, Gulf Research & Development Company, Pittsburgh, Pa.
(Read by L. L. Nettleton in Tulsa, by G. B. Lamb in Houston)

Methods of operation which were used for an extensive gravimeter survey in the foothills belt of Alberta, are described. The paper is more concerned with a relatively small but essential part of the work in the rugged area of the foothills which was accomplished by special methods using horseback travel.

The gravity observations were made with a newly developed, small type gravimeter similar in general design to the previously described, larger, Gulf instrument. Much of the surveying for both horizontal and vertical control was carried out by transit. Terrain corrections were large but appear to have been quite adequate, as indicated by the regularity of results. Some remarks are included on the working seasons in the foothills and in the plains area to the east.

12. Gravity and Magnetic Investigations at the Grand Saline Salt Dome

Jack W. Peters and Albert F. Dugan, Magnolia Petroleum Company, Dallas, Texas.
(Read by Mr. Peters in Tulsa, Houston, and Dallas)

In order to secure additional information on the physical properties of a typical East Texas salt dome, detailed gravity and magnetic surveys were made at

the Grand Saline Salt Dome. The results of these surveys are believed to be of particular interest because in addition to the surface gravity and magnetic observations, gravity observations were made in the Morton Salt Mine.

A theoretical mass distribution was computed reflecting surface and subsurface gravity anomalies which reasonably coincided with the observed surface and subsurface anomalies. This theoretical mass distribution is offered only as a possible solution to the geological and geophysical data, and is not considered to be the unique solution.

13. Torsion Balance Step Anomalies in Northern Tillman County, Oklahoma.

H. Klaus, Klaus Exploration Company, Lubbock, Texas.

(Read by Mr. Klaus in Tulsa)

The results of an experimental torsion balance survey in Southwestern Oklahoma are shown by means of a gradient-curvature map, a gravity map, two second derivative contour maps, and gravity and second derivative profiles. The writer's interpretation of these data is embodied in a hypothetical geological profile, which shows a 6,000′ normal fault at the southwestern edge of the Wichita Mountains System. This would imply a thick sedimentary section in the downthrown block, which might be of economic interest. A comparison of the gravity and second derivative data has a possible bearing on the orogeny of the Wichita Mountains.

14. The Relative Abundance of the Carbon Isotopes in Petroleum.

S. S. West, Stanolind Oil and Gas Company, Tulsa, Oklahoma.

(Read by Dr. West in Tulsa)

The relative abundance of the carbon isotopes has been measured in samples of oil and gas taken from 32 wells of the Silica and Ellinwood fields of Barton and Rice Counties, Kansas, in 3 other oil samples from Oklahoma, Texas and Wyoming, and in surface vegetation and carbon dioxide absorbed on soil. For the Silica and Ellinwood samples $C_{12}/C_{13}=94.1\pm0.5$. The abundance-ratios for the samples from other sources differed so little from this value that it was concluded that this sort of measurement will not serve to determine the source of carbon compounds in nature.

15. How the Properties of Nuclear Radiation Influence Radioactivity Logs.

R. E. Fearon, Tulsa, Oklahoma.

(Read by Mr. Fearon in Tulsa)

The effect of penetrating power of nuclear radiation, the amount of corpuscular energy, and the ability of various nuclear radiations to excite secondary processes is discussed with respect to gamma ray well logging. The importance of the transformations to which neutrons are susceptible is discussed with respect to their influence on neutron logs. Experimental demonstrations of some of the common properties of nuclear rays were given.

16. An Investigation of Natural Earth Currents.

R. S. Dahlberg, Jr., Carter Oil Company, Tulsa, Oklahoma.

(Read by Mr. Dahlberg in Tulsa, by Glenn M. McGuckin in Dallas)

An attempt was made to obtain relative apparent resistivities by measuring the potential gradients produced by natural earth currents. Alternating components in the range 0.5 to 10 cps. were used.

The results of two surveys in Oklahoma are shown and various perturbing factors are discussed. The conclusion is reached that the method is not likely to replace conventional resistivity methods.

17. On Well Velocity Data and Their Application to Reflection Shooting.

P. E. Narvarte, Petty Geophysical Engineering Company, San Antonio, Texas.

(Read by Mr. Narvarte in Tulsa and Houston)

The use of smooth velocity-depth and velocity-time relations based on actual velocity distribution in the section are well known, and rigorous mathematical solutions for these conditions have been set forth in the past. Certain weaknesses and limitations of this method are pointed out and typical examples of velocity distribution in various geologic sections are given.

A derived time-depth relation is proposed satisfying measured velocity data that would be applicable over wide areas. Advantages and limitations in the application of this relation are discussed.

18. Lethal Effects on Certain Marine Life of the Detonation of Explosives in Water.

James Nelson Gowanloch and John E. McDougall, Department of Wild Life and Fisheries, Louisiana.

(Read by Mr. McDougall in Houston)

Physiologically stabilized croakers (*Micropogon undulatus*) and shrimp (*Penaeus setiferus*) were subjected to dynamite shock effects in fish cars at 50, 100, 150, 200, 300 and 400 feet. Special seismometers recorded the relative amplitudes and a relative pressure curve was derived. Two 800 pound charges and one 200 pound charge of 60% gelatine dynamite were detonated, each charge affecting a separate sequence of fish cars. Careful examinations were made of the specimens immediately before and after each "shot" and at 24 and 48 hour intervals thereafter.

Shrimp were not harmed. All fish were killed within 150 feet of each blast. None were killed 200 feet away.

19. Recent Developments in Geochemical Prospecting for Petroleum.

Leo Horvitz, Horvitz Research Laboratories, Houston, Texas.

(Read by Dr. Horvitz in Houston and Dallas)

A number of surveys completed during the past two years indicate that the geochemical prospecting technique can be applied successfully only when an area is explored which is sufficiently large to enable ready distinction of the anomaly from the background.

Geochemical data obtained over the Jackson Ranch, Chambers County, Texas, together with a seismic survey of a portion of this area suggest a procedure whereby the two techniques may be used; one to supplement the other.

20. The Principle of Variation in Path with an Application to Structural Mapping.

H. M. Evjen, The Elflex Company, Houston, Texas.

(Read by Dr. Evjen in Houston)

A general functional analysis of the low frequency electric exploration problem is presented. The theory is applied to some field data where a fair degree of subsurface control exists.

21. A Resistolog Survey of the Loma Alto-Seven Sisters Area of McMullen and Duval Counties, Texas.

Thomas S. West, Henderson Coquat Interests, Three Rivers, Texas, and Clarence C. Beacham, Somerset, Ohio.

(Read by Mr. West in Houston)

Additional field results with the Resistolog procedure are shown. This method of direct current resistivity prospecting was described in the October 1944 issue of GEOPHYSICS. Precise measurement of subsurface electrical properties is attained by eliminating from the data the influence of surface or near surface variations in resistivity.

Detailed field surveys under known or subsequently determined conditions along with electric logs of wells and other geological information are shown for the Loma Alto-Seven Sisters area of McMullen and Duval Counties, Texas. Several cases of direct detection of oil saturation at depths of 2200 and 2500 feet are indicated and successful structural correlations are shown for this area.

22. The Narrow Band Resistance-Coupled Amplifier.

Laurence G. Cowles, The Texas Company, Houston, Texas.

(Read by Mr. Cowles in Houston)

A method for the design of the amplifier's coupling circuit is presented in a form permitting the selection of circuit constants directly from a specified band width, peak frequency, and peak frequency coupling loss. The design procedure is illustrated by several practical examples and the limitations of the narrow band amplifier are discussed.

23. Repeated P-Waves in Seismic Exploration of Water Covered Areas.

Roy L. Lay, The Texas Company, Houston, Texas.

(Read by Mr. Lay in Houston and Dallas)

A secondary, and even a tertiary, P-Wave has been observed under certain conditions in seismic exploration of water covered areas. It is shown that these events are caused by an oscillation at the shot point. The procedure for eliminating these disturbing phenomena is described.

24. Effect of Ray Curvature upon Seismic Interpretations.

E. J. Stulken, Geophysical Service, Inc., Dallas, Texas.

(Read by Mr. Stulken in Houston and Dallas)

For a specific family of velocity functions inaccuracies of velocity computations due to neglect of curvature are illustrated graphically as variables dependent on spread and travel time. Discrepancies traceable to use of straight line methods of depth and dip determination are likewise described.

Application of common analytical expressions for velocity to orthodox curved path computations fails to guarantee accurate results in some instances. Errors introduced by neglecting pertinent irregularities in observed data may outweigh the gain in accuracy attributed to the rigorous method. It is indicated that existence of sloping "isovelocity" surfaces may invalidate the usual curved path procedure.

On the basis of these aspects of the problem an attempt is made to evaluate the net importance of considering ray curvature.

25. Refraction Exploration in West Texas.

Sidon Harris and Gwendolyn Peabody, Southern Exploration Service, Fort Worth, Texas.

(Read by Dr. Harris in Dallas)

A brief historical summary of refraction shooting is given with special emphasis on West Texas. A general discussion of more recent techniques is presented with a few simplified methods of computation as applied to the Edwards Plateau and other localized areas in West Texas. A brief description of field problems and techniques is given.

26. Informal Discussion of Explosive Hazards on Seismograph Crews.

G. M. Kintz and Staff, Safety Division, U. S. Bureau of Mines, Dallas, Texas.

(Conducted by Mr. Kintz in Dallas)

READ BY TITLE ONLY

27. Geophysical History of the Heidelberg Field.

Paul C. Reed, Gulf Research & Development Company, Houston, Texas.

28. Application of Continuous Profiling for Refraction Shooting.

A. J. Barthelmes, Seismograph Service Corporation, Tulsa, Oklahoma.

A method of refraction shooting is developed for the purpose of investigating sub-surface structures by utilizing the principle of continuous profiling now generally in use for detailed and more accurate reflection surveys.

The basic assumptions and the general theory, which will allow individual depth determinations for all geophone locations, are discussed. The practical application is illustrated with sample records, calculations, and cross sections. Several field techniques are discussed and analyzed, including some figures on production and field efficiency.

29. Radiometric Determination of Potassium in Rocks and Soils.

Roland F. Beers, Geotechnical Corporation, Cambridge, Mass.

The radioactive isotope of potassium $_{19}K^{40}$ emits beta and gamma rays which offer a convenient means of quantitatively determining the potassium content of rocks and soils. When the radiations from uranium and thorium minerals in the samples approach equality with the number from potassium, measurement of both beta and gamma rays are required for differentiation.

The paper describes a method of making both beta and gamma measurements with the same apparatus. Calibrations and corrections for absorption of radiation by the sample are given. The influence of potassium radiations on gamma ray well logs is discussed.

30. A Method of Determining Dip, Strike, and Impact Point for Steeply Dipping Beds.

N. N. Zirbel, Independent Exploration Company, Houston, Texas.

A method of determining the dip, strike, and impact point for steeply dipping beds which is considered simple enough for use in normal field computation is described.

31. Depth-Displacement Slide Rule.

W. R. Fillippone, United Geophysical Company, Pasadena, California.

A slide rule is described, based on formulae for circular arc ray paths, to compute depth and displacement of seismic reflectors when time of reflection, angle of dip and velocity-depth distribution are known. The rule may be used to compute horizontal and vertical displacement for reflectors on point-plotted sections if dips do not exceed five degrees. An alternative is a modification of a standard log-log trig slide rule which serves the same purpose.

32. Some Physical Considerations Bearing upon the Theory of Isostasy.

M. King Hubbert, Shell Oil Company, Houston, Texas.

While the theory of isostasy, as a generality, has by now gained practically universal acceptance among the students of the earth, there is as yet no comparable agreement as to the significance of isostasy in various geological processes, and of what phenomena may or may not be ascribed to isostasy as a cause.

The purpose of this paper is to review some of the physical aspects of the isostasy problems and to deduce criteria for distinguishing between those phenomena which are manifestations of isostasy and others which are not. These criteria will be in part mechanical, and in part thermodynamical. By this means it will be shown that diastrophism (including volcanism) and erosion are the truly fundamental dynamical processes of the earth, in comparison with which isostasy is but a minor and secondary adjustment phenomenon.

33. Organization of Geophysical Parties for Foreign Exploration.

Charles H. Dresbach, Western Gulf Oil Company, Los Angeles, California.

Current and future requirements of petroleum have produced a strong demand for American personnel, equipment and technique to be employed in the world-wide search for oil. Different, and sometimes much more difficult conditions are frequently encountered from those customarily met in the exploration for oil in the United States. A brief consideration of some of these factors is the purpose of this paper. It is concluded that while careful preliminary planning and the design of equipment in the light of accurate information on conditions to be encountered are highly vital factors, the demonstrated and trustworthy character of the personnel conducting the operations is the biggest guarantee of success in the undertaking.

34. Studies on Seismic Waves: I. Reflection and Refraction of Plane Waves.

C. Y. Fu, United Geophysical Company, Pasadena, California.

By taking the apparent velocity along the boundary as the parameter instead of the angle of incidence, the equations for the different wave amplitudes may be put in more symmetrical forms. In this way, it is more convenient to discuss both the body waves and the Rayleigh waves at the same time. A defect of plotting the square root of the wave intensity against the angles is also discussed. When the reflection or refraction coefficient is not real, the meaning of the intensity as obtained by squaring the amplitude of the wave needs clarification.

35. Studies on Seismic Waves: II. On Rayleigh Waves in a Superficial Layer.

C. Y. Fu, United Geophysical Company, Pasadena, California.

Lamb's method in the theory of the plate is extended to the case in which one of the surfaces is not free. The resulting determinantal relation is similar to that of Sezawa. A method of simplifying this determinant is developed and special cases of the frequency-velocity relation are discussed. Even when the thickness of the layer is as small as a wave length, the interaction of the upper and lower boundaries of the layer is quite slight and Rayleigh waves and Stoneley's waves may be discussed separately. A few points in connection with the application of this frequency relation to the ground roll problem are also discussed.

36. The Interpretation of Well Shot Data. III. Simplest Cases of Lateral Velocity Variation.

C. Hewitt Dix, United Geophysical Company, Pasadena, California.

The case of the linear velocity-depth relation $V=V_d+az$ is generalized to include bx giving the lateral variation. By a rotation of coordinates through an angle $\theta=\tan^{-1}(b/a)$, $V=V_d+az+bx$ becomes $V=V_d+(a/\cos\theta)z$. If one well is shot from several shot points in line the horizontal distance from the well to the place where the line of centers of ray circles intersects a shallow level datum is approximately $(1/2)(z^2/d)$ where d is distance from well to point on datum corresponding to minimum travel time from points on datum to well point at depth z. The approximate height of this line of centers at the well can be found so we can find the tilt of the datum. More general cases are discussed.

37. Motion of an Elastic Sphere in an Acoustic Wave Field in Fluids.

Alfred Wolf, Geophysical Research Corporation, Tulsa, Oklahoma.

The theory of the motion of a sphere in the field of plane acoustic waves developed in a recent paper[1] is valid strictly only when the moduli of elasticity of the sphere are very great compared to the moduli of the medium. In the present paper, the theory is extended to the case of an elastic sphere in a fluid which may have a modulus of compressibility of any value. The methods used are those of the previous paper. The results obtained are quite complicated but can be simplified considerably when the modulus of compressibility of the fluid is sufficiently small, so that only the first order of the ratio of the compressibility modulus of the fluid and the elastic moduli of the sphere need be considered.

[1] GEOPHYSICS, Vol. X, No. 1 (Jan. 1945), pp. 91–109.

38. Notes on Formulation of Seismic Velocity.
Joseph L. Adler, Independent Exploration Company, Houston, Texas.

A method is presented for determining from reversed refraction profiles the best fitting value of the factor K, where $V=V_0+KZ$. Charts are included which reduce to a few minutes the time required for the computation. Velocities determined by well-shooting support the following conclusions:

Use of this formula in lieu of actual interval velocities to simplify both refraction and reflection computing generally introduces little error within the vertical limits of the data to which the factor K has been fitted. Extrapolation of the velocity curve may result in gross inaccuracy and a logarithmic type of curve fitted to available well-shooting or $T-\Delta T$ data affords a better basis for extrapolation. After such extrapolation an over-all best fitting value for K can be determined which will produce less error than the value of K determined strictly in the region of observed data.

39. Evaluation of Single Leases by Seismograph.
F. L. Bishop, Tulsa, Oklahoma.

40. Study of Ground Motion Due to Dynamite Explosions.
J. E. Walker, Shell Oil Company, Houston, Texas.

41. Interpretation of Gravity Data.
Robert H. Ray, Houston, Texas.

MINUTES

ANNUAL BUSINESS MEETING

April 4, 1945

The annual Business Meeting of the Society of Exploration Geophysicists was held in the Ball Room on the mezzanine floor of the Mayo Hotel, Tulsa, Oklahoma. The meeting was presided over by President Rust and was called to order at 8:40 A.M.

Mr. Rust commented on the fine quality as well as the abundance of papers secured for the meeting by Mr. Henry C. Cortes, Program Chairman, and his district representatives.

The minutes for the Annual Business Meeting for 1944 were read by the Secretary and accepted. The Treasurer's report for 1944 was read and accepted. The Secretary-Treasurer also read a membership report showing at the end of 1944 a total of 934 active members, 189 associate members and 7 student members, for a total Society membership of 1130. This was an increase of 129 members over 1943.

The Editor's report was read and accepted.

The President complimented Dr. Joseph Sharpe on his fine editorship and high quality of publications over the last three years.

Dr. Rust spoke on a reallocation of radio frequencies by the Federal Communications Commission.

Dr. Rust spoke briefly on recent legislation in both Oklahoma and Texas which would greatly hamper the operation of geophysical surveying. He mentioned briefly what had been done to prevent this legislation, but encouraged everyone to help out who possibly could.

OFFICERS FOR THE YEAR ENDING APRIL, 1946

W. M. RUST, JR., Past President

J. J. JAKOSKY, Vice President

HENRY C. CORTES, President

CECIL H. GREEN, Secretary-Treasurer

L. L. NETTLETON, Editor

Dr. Rust mentioned a recent request from a representative of the Bureau of Mines for the formulation of a set of safety rules which would be accepted by the geophysical industry as a whole. He stated that Mr. Ralph S. Jackson has been placed in charge of a committee of his own selection to look into this matter, and any suggestions on the part of members to him will be appreciated.

The President brought up the question of district representatives of the Society and stated that for the purpose of conducting Society business the chairman of each areal Program Committee as designated by Mr. Henry C. Cortes, Program Chairman, would serve in the capacity of district representative. The following are area representatives:

Houston	R. S. Jackson
Dallas	Cecil H. Green
Pittsburgh	L. L. Nettleton
Pacific Coast	O. C. Lester, Jr.
San Antonio	P. E. Narvarte
New York-New England	R. F. Weichert, Jr.
Fort Worth-Colorado	John H. Wilson

President Rust read the election results. Votes cast for the officers elected for the new year were:

President		*Vice President*		*Editor*		*Secretary-Treasurer*	
Cortes	328	Jakosky	312	Nettleton	434	Green	287
Westby	221	Salvatori	228	Ricker	118	Romberg	259

Messrs. Cortes, Jakosky, Nettleton and Green were formally declared elected.

A total of 605 votes were cast, with 560 votes being valid; 12 ballots were not valid due to absence of signature, 30 ballots were declared not valid because of dues in arrears, and 3 ballots were not valid because of being cast too late.

There being no further business, the annual Business Meeting of the Society was adjourned at 9:10 A.M.

W. HARLAN TAYLOR, *Secretary*

ANNUAL REPORT OF THE SECRETARY-TREASURER OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS

BALANCE SHEET

SOCIETY OF EXPLORATION GEOPHYSICISTS—HOUSTON, TEXAS

December 31, 1944

ASSETS

Current			
Cash			
In Banks		$10,602.08	
Accounts Receivable			
Membership Dues	$538.50		
Advertising	275.50		
Reprints	200.10		
Back Numbers	151.60		
Subscriptions	62.90		
Other	77.27	1,305.87	$11,907.95
Investment			
Farm and Home Savings and Loan Association of Missouri—Fully Paid Certificate		$ 5,000.00	
U. S. Savings Bonds		4,960.00	9,960.00
Office Equipment			
Cost		$ 101.17	
Less: Reserve for Depreciation		43.75	57.42
			$21,925.37

LIABILITIES

Current			
Accounts Payable			
For Expenses, etc.		$ 162.06	
Withholding Tax		151.34	$ 313.40
Deferred Income			
Prepaid Subscriptions		$ 514.00	
Prepaid Dues		110.68	
Prepaid Advertising		27.10	651.78
Surplus			
Balance January 1, 1944		$17,828.17	
Add			
Increase from Current Year Operations—Per Statement of Income and Expense	$3,139.31		
Deduct			
Adjustment of 1943:			
Dues Receivable	$6.00		
Reprints Receivable	1.29	7.29	3,132.02	20,960.19
			$21,925.37

INCOME AND EXPENSE
SOCIETY OF EXPLORATION GEOPHYSICISTS—HOUSTON, TEXAS
Year Ended December 31, 1944

INCOME

Membership Dues			$5,665.50	
Publications:				
Advertising	$3,326.85			
Subscriptions	1,336.75			
Back Numbers	808.80			
Reprints	410.18		5,882.58	
Other Income:				
Interest Received	$ 254.38			
Commissions on Publications	1.20		255.58	$11,803.66
Less: Discounts to Colleges, etc. on Subscriptions and Back Numbers				181.30 $11,622.36

COSTS AND EXPENSES

Publication Costs:				
GEOPHYSICS:				
Vol. IX No. 1—158 Pages	$1,004.77			
No. 2—190 Pages	1,081.33			
No. 3—182 Pages	1,272.64			
No. 4—192 Pages	1,325.71	$4,684.45		
Reprints		396.71		
Indices Vol. VII and VIII		47.64		
Binding		40.60		
Drawings		20.00	$ 5,189.40	
Expenses—Per detail schedule			3,293.65	$ 8,483.05
Excess of Income over Costs and Expenses				$ 3,139.31

EXPENSES

Salary—Business Manager			$ 1,200.00
Commissions:			
Advertising:			
Business Manager	$ 456.71		
Agencies	388.37	$ 845.08	
Subscriptions, etc.—Agencies		54.20	899.28
Postage and Box Rent			337.13
Stationery, Office Supplies and Expenses			326.62
Freight and Express			149.43
Bad Debts			137.50
Auditing			108.00
Telephone and Telegraph			94.14
Bond Premiums			15.00
Society Card—A.A.P.G.			15.00
Depreciation			10.12
Bank Charges			1.43
			$ 3,293.65

Respectfully submitted,
W. HARLAN TAYLOR, *Secretary-Treasurer*

PACIFIC COAST MEETING

A one-day technical meeting of the Pacific Coast Group of the S.E.G. will be held in the Gold Room of the Ambassador Hotel, Los Angeles, Wednesday, November 7, 1945, one day prior to the sectional meeting of the A.A.P.G. All Pacific Coast members are cordially invited to attend.

The Program Committee invites new material by Pacific Coast authors for presentation at this meeting and future publication in the Bulletin and requests it be advised by such authors as soon as possible in order to facilitate arrangement of the program. Titles and abstracts should be in the hands of the Committee not later than October first.

Mr. E. H. Vallat, chairman of the Committee on Arrangements, has offered all possible assistance to out of town members in securing room reservations. Those desiring such assistance should advise him at as early a date as possible.

PERSONAL ITEMS

H. M. HOUGHTON, formerly with Tide Water, is serving as Geophysical Consultant with the U. S. Engineers at Santa Fe, New Mexico. His postal address is Box 1663.

LELAND SNOW, Seismic Party Chief with Petty, is in South America. He may be reached c/o Richmond Exploration Co., Aptdo. 93, Maracaibo, Venezuela.

PAUL BROWNING is employed by the Creole Petroleum Corp., Maracaibo, Venezuela, S. A., as Petroleum Engineer.

C. L. Doss of the Geotechnical Corp. has moved from Dallas to Cambridge, Mass., where he will serve as Supt. of Instrument Development in the Research Laboratory. His address is 149 Sidney St., Cambridge 39.

B. W. POEPPEL, Observer with SSC of Dela., should be addressed in care of the company at Aptdo. 1488, Caracas, Venezuela.

FRANCIS A. ROBERTS, Computer with Carter, is stationed in Saskatoon, Sask., Canada, with the postal address Box 67.

IRVIN FRAZIER, 1645 Bedford Rd., San Marino 9, Calif., has advised the Society that he has a copy of Vol. I, No. 1, of GEOPHYSICS, now out of print, which he will sell for $5. The check should be sent direct to Mr. Frazier.

MICHAEL J. WALCZAK is Dist. Seis. Supervisor for Atlantic, with offices at 431 Wyoming National Bank Bldg., Casper, Wyo.

LT. COL. JOHN V. LONG is stationed at Fort Ord., Calif., Hq. 2nd Bn., 1st Regt.

LT. CMDR. JOHN H. CROWELL, USNR, has changed his residence from Chevy Chase to 5510 Brite Dr., Bethesda, Md.

R. W. LINDSEY is Party Chief with the Carr Geophysical Co., 1334 Commerce Bldg., Houston 2, Tex.

ROBERT BAUM is Party Chief with SSC, 709 Kennedy Bldg., Tulsa, Okla.

A. K. MEHTA has left the States for India. He may be addressed at 197 Park St., Calcutta.

L. C. PASLAY has left the Naval Ordnance Laboratory in Washington, D. C., and has returned to Dallas, Texas, to resume his duties as Director of Research for the National Geophysical Co., Inc. His home address is 4012 University Blvd.

O. G. HOLEKAMP is Seismologist with the Shell Oil Co., Inc. He may be addressed at P. O. Box 2099, Houston 1, Tex.

ARNOLD E. BRAYTON, newly-elected associate member, is with Surinaam Bauxite Maatschappij, Paranam Works, Paramaribo, Suriname, S. A.

KARL H. SCHMIDT and V. T. DONNELLY, formerly of the Arkansas Fuel Oil Co., have established the Petroleum Service Company, with offices in the Alamo National Bldg., San Antonio, Tex. The new firm will run core and bottom hole sample analyses.

A. F. BECK has resigned from Cities Service to accept a position with the Imperial Oil Co., 56 Church St., Toronto, Ontario, Canada. The change was made effective June 1.

FRANK R. KITTREDGE, Petty Party Chief, has offices at 1205 Hunt Bldg., Tulsa, Okla.

NORVEL DOUGLAS is Owner of the Douglas Engineering Co., 7114 Hines Blvd., Dallas 9, Tex.

PAUL M. TUCKER is working for the Standard Oil of Cuba, Aptdo. 1303, Havana, Cuba.

MAJOR GLEN D. LAMBERT has been transferred to the 63rd AAA Group, Seattle, Wash.

MARTIN EICHELBERGER, JR., United Party Chief, is located at 1952 Waltonia Dr., Montrose, Calif.

MAJOR LEONARD F. UHRIG may be addressed c/o Nell C. Uhrig, 3801 Villanova, Houston 5, Tex.

E. J. HANDLEY, formerly with British-American, has accepted employment as Geophysicist for Shell Oil Co., Inc. His residence address is 2935 S. Cincinnati, Tulsa, Okla.

L. M. MOTT-SMITH is Physicist in the Applied Physics Lab. of Johns Hopkins Univ. His residence address is 3000 Tennyson St., NW, Washington 15, D. C.

C. H. MCALISTER is Chief Geophysicist for the Union Sulphur Co., Sulphur, La.

J. P. GARNER, Texas Co. Party Chief, should be addressed in care of that company at P. O. Box 2332, Houston 1, Tex.

IRL SANDIDGE, JR., is Associate Engineer with the Federal Power Commission. His mailing address is Box 1112, Ft. Worth, Tex.

W. B. HOGG, Supervisor for National Geophysical Co., Inc., has returned to Dallas from Little Rock, Ark. His address is 5517 Purdue, Dallas, Tex.

C. E. WILLIAMS, formerly with the Texas Co., has been Recorder for the American Exploration Co., P. O. Box 6296, Houston, Tex., since last October.

JOE L. FERGUSON, of the Brown Geophysical Co., has been transferred from Tallahassee, Fla., to Williamston, Mich. Offices in the latter city are in the Peoples State Bank Bldg.

MAJOR MERLE C. BOWSKY should be addressed at APO 655, c/o Postmaster, New York, N. Y.

K. ERGIN and PERTEV I. BEDIZ have returned to Turkey, and may be addressed c/o M. T. A. Enstitusu, Ankara.

R. HENQUET has been made Vice President and General Manager of the Schlumberger Well Surveying Corp., P. O. Box 2175, Houston 1, Tex.

LT. FIELDING L. MITCHELL is serving under the Director of Naval Petroleum Reserves. He may be addressed in care of Fleet Post Office, San Francisco, Calif.

J. B. SOUTHER, Consulting Geologist and Geophysicist, advised the Society on April 19 that he would be in San Pedro Sula, Honduras, for a year. He may be addressed at 1930 F St., Lincoln, Nebr.

WILLIAM M. WELLS, Consulting Geophysicist, is Owner of Wells Gravity Surveys. Offices of the new firm are at 209 First Natl. Bk. Bldg., Shreveport 23, La.

ROBERT L. CRAIG is working for the Standard Oil Co. of Cuba, Aptdo. 1303, Havana, Cuba.

DAVID SHEFFET, who has been serving in the Naval Ordnance Laboratory at Washington, D. C., for the past several years, has returned to his position as Engineer for the Stanolind Oil and Gas Co., Box 591, Tulsa, Okla.

C. E. COLVIN has notified the Society of his change of address from 1702 Tower Pet. Bldg., Dallas, to 2008 Main St., Miles City, Mont.

G. C. HOWARD, Computer for Carter, has been transferred from Canton, Miss., to Green River, Wyo., where his postal address is Box 471.

MAYNARD W. HARDING, Personnel Manager for United Geophysical, has notified the Society of a number of incorrect listings appearing in the annual membership list. With United Geophysical Co., S. A., in foreign service, are WAYNE H. DENNING, Resident Manager, in Bahia, Brazil; ROBERT H. MANSFIELD, Seismologist, in Caracas, Venezuela; LAWRENCE K. MORRIS, Geophysical Supervisor, in Punta Arenas, Magallanes, Chile; and STEWART C. PALMERSTON and JAMES A. SMITH, both Party Chiefs in Barranquilla, Colombia. C. RUSSELL HALE is Co-ordinator of Foreign Operations for United, while KENNETH L. GARDNER is no longer with the company, and FLINT H. AGEE, formerly with National Geophysical Co., has joined United as Seismic Party Chief. J. A. LEGGE, JR., NASH H. MILLER, W. H. MYERS, HENRY F. WISE, and JOHN R. WOOLSON are Party Chiefs, while K. A. ROBERTSON has been advanced to the status of Supervisor. E. A. PIELEMEIER, Vice-President of United, was incorrectly listed as Secretary-Treasurer.

C. D. KEEN has notified the Society of his change of address from Shreveport to Leland, Mich., where his postal address is Box 61.

MICHAEL ALLON, of the Gulf Res. and Dev. Co., has been transferred from Lovington, N. M., to Pincher Creek, Alberta, Canada, with the postal address Box G-3.

LT. JOHN W. FLUDE, USNR, has been transferred from Bayonne, N. J., to Galveston, Texas. His postal address is Box 330.

W. E. FRANKS is Sr. Geophysicist for the Creole Pet. Corp., Aptdo. 1329, Caracas, Venezuela, S. A.

LT. C. C. LUDWICK is with Sq. A-462nd AAF Base Unit, Camp Pinedale, Fresno, Calif.

ROLAND F. BEERS, President of the Geotechnical Corp., has for the past year been acting as Consulting Geophysicist to the United States Geological Survey.

HOWARD ITTEN, Stanolind Party Chief, has been transferred from Corsicana to Crockett, Texas, where his mailing address is Box 551.

Secrecy has recently been lifted by the government on a new device utilizing electronic and radioactivity principles for the measurement of thickness of solids, metallic or non-metallic, and for determining liquid level and liquid density. This device is called "The Penetron."

The Penetron is a development of the Texaco Development Corporation, largely by Dr. Gerhard Herzog, and Engineering Laboratories, Inc., Tulsa, has been exclusively licensed for the sale and manufacture of the instrument. The instrument depends upon the bombardment of the object being tested with gamma rays derived from a needle containing a minute amount of radium. The rays are scattered by the electrons of the atoms in the material being inspected and some are scattered backward on the same side as they entered. The intensity of this back-scattered radiation is a direct function of the thickness of the material at the spot being measured. Liquid levels and liquid densities also may be determined.

The device is particularly useful for inspection of high pressure pipe lines, boiler tubes, towers, pressure vessels, etc., and for determining interfaces of fluids of various densities or liquid levels in sealed containers. Accurate readings are made in 25 seconds with over 150 inspections per working day possible. Its applications are as wide as industry itself.

SIDNEY SCHAFER, formerly Geophysicist for the Pan American Production Company, has opened an office as a Consulting Geophysicist and may be addressed at 1248 Mellie Esperson Building, Houston, Texas.

PROFESSIONAL DIRECTORY

Space reserved for members only. For rates
apply to E. Stiles
Society of Exploration Geophysicists
Hamilton, Texas

E. E. ROSAIRE
Geochemical Prospecting
SUBTERREX
2711 Westheimer Road
Houston 6, Texas

JOHN H. WILSON
Geologist and Geophysicist
Independent Exploration Company
2210 Fort Worth National Bank Building
FORT WORTH, TEXAS

JOHN S. IVY
Niels Esperson Building
HOUSTON, TEXAS

JOSEPH L. ADLER
Geologist and Geophysicist
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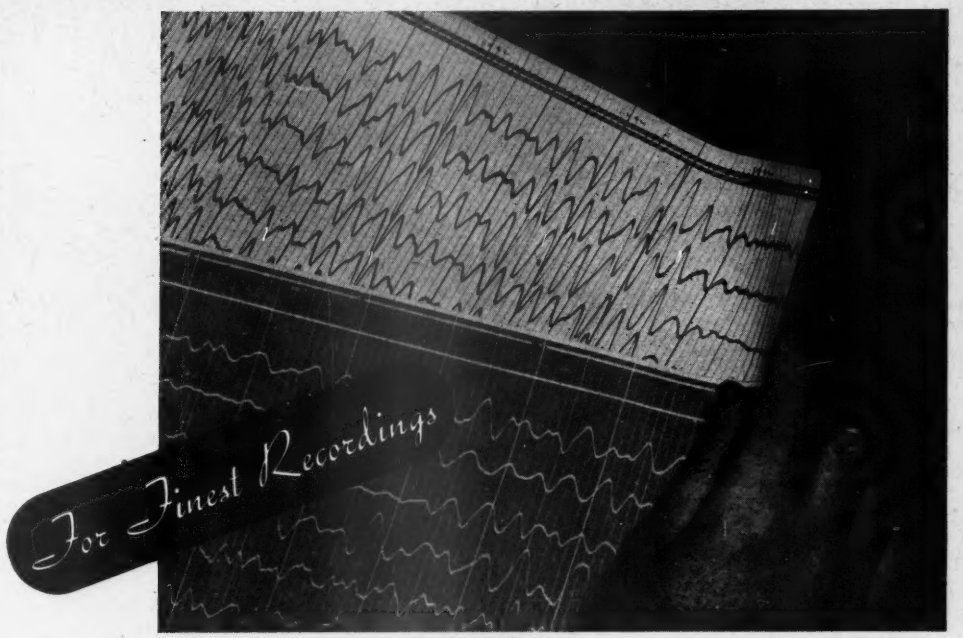

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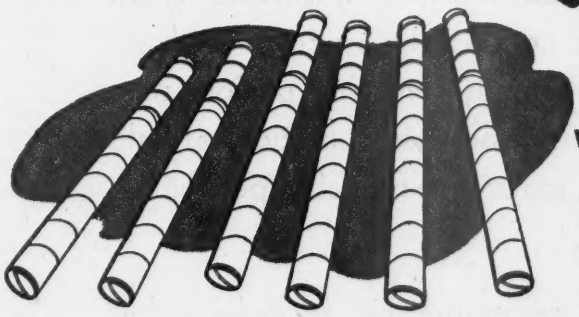

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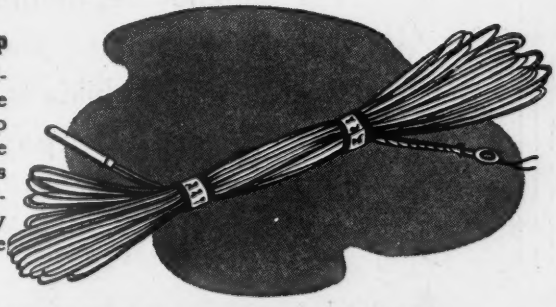

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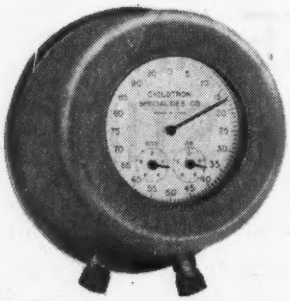

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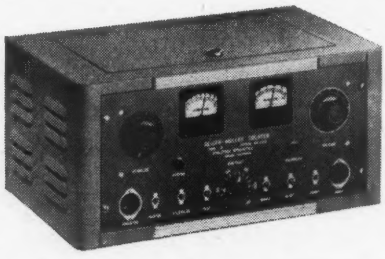

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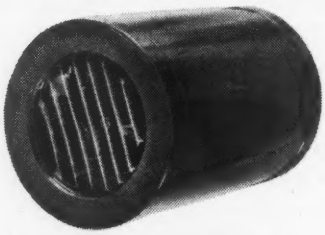

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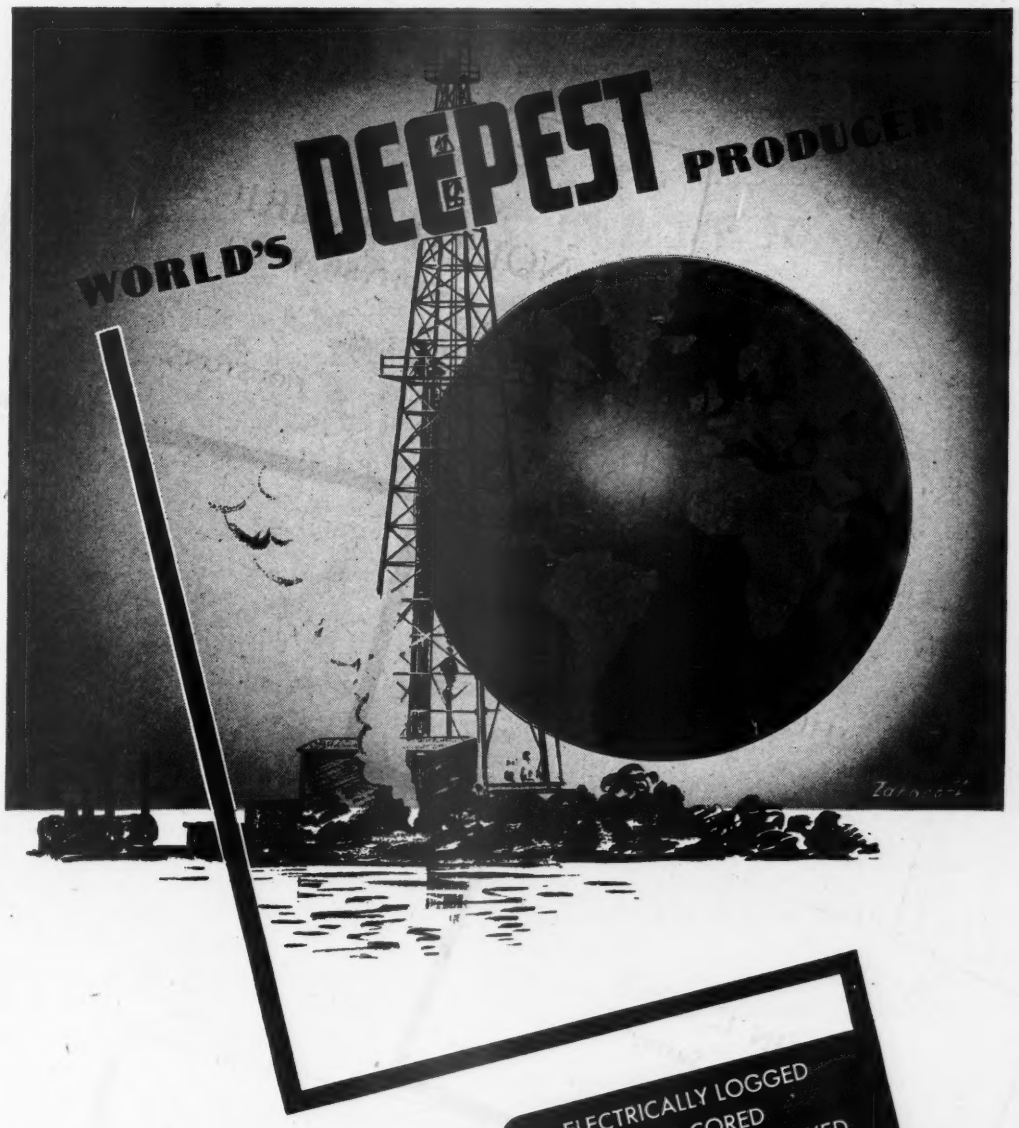

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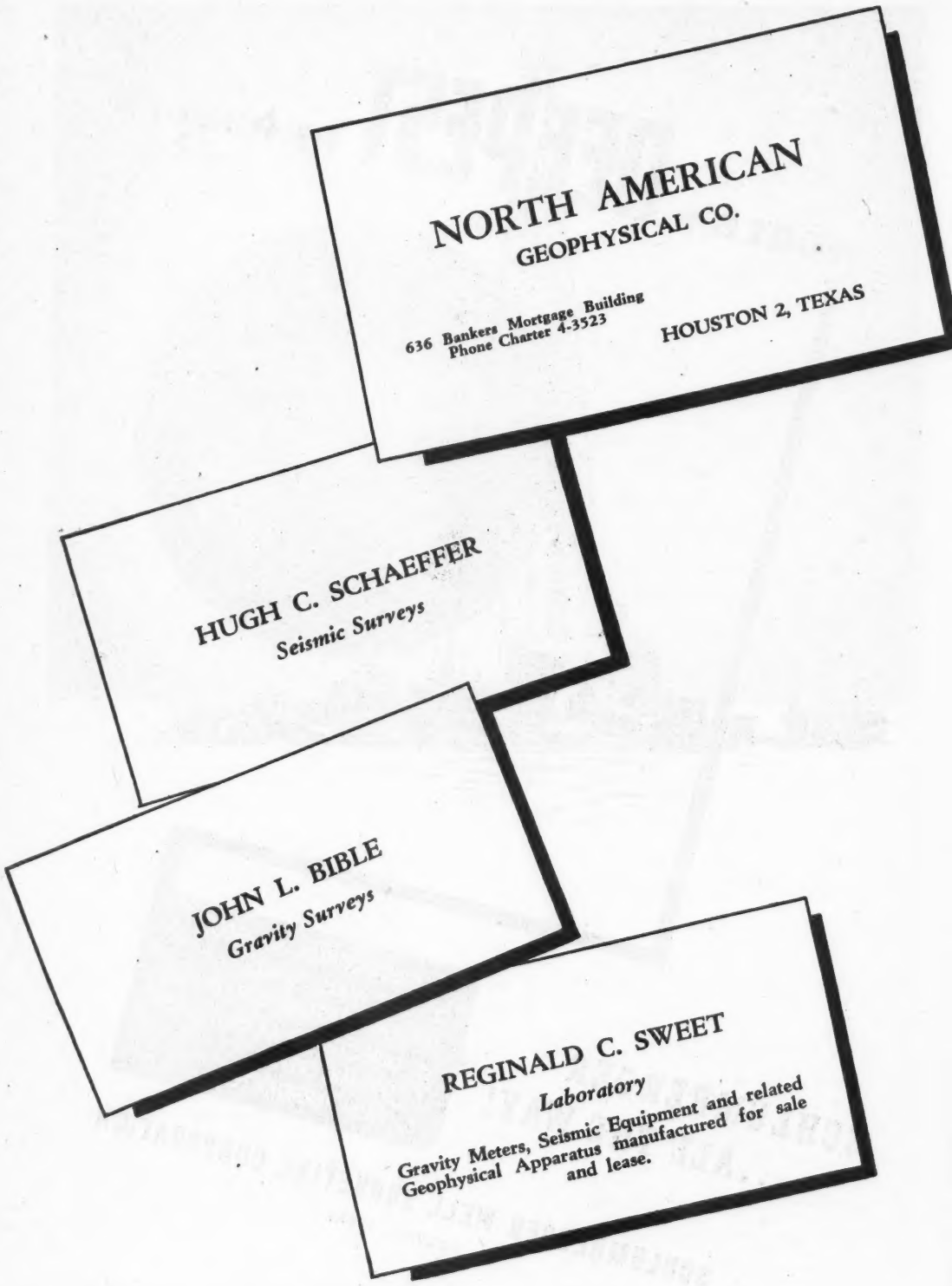
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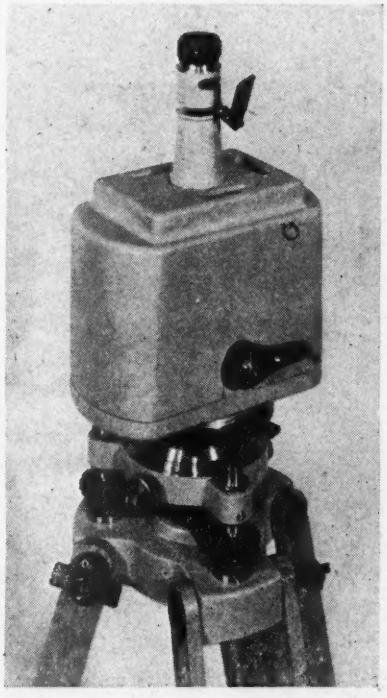

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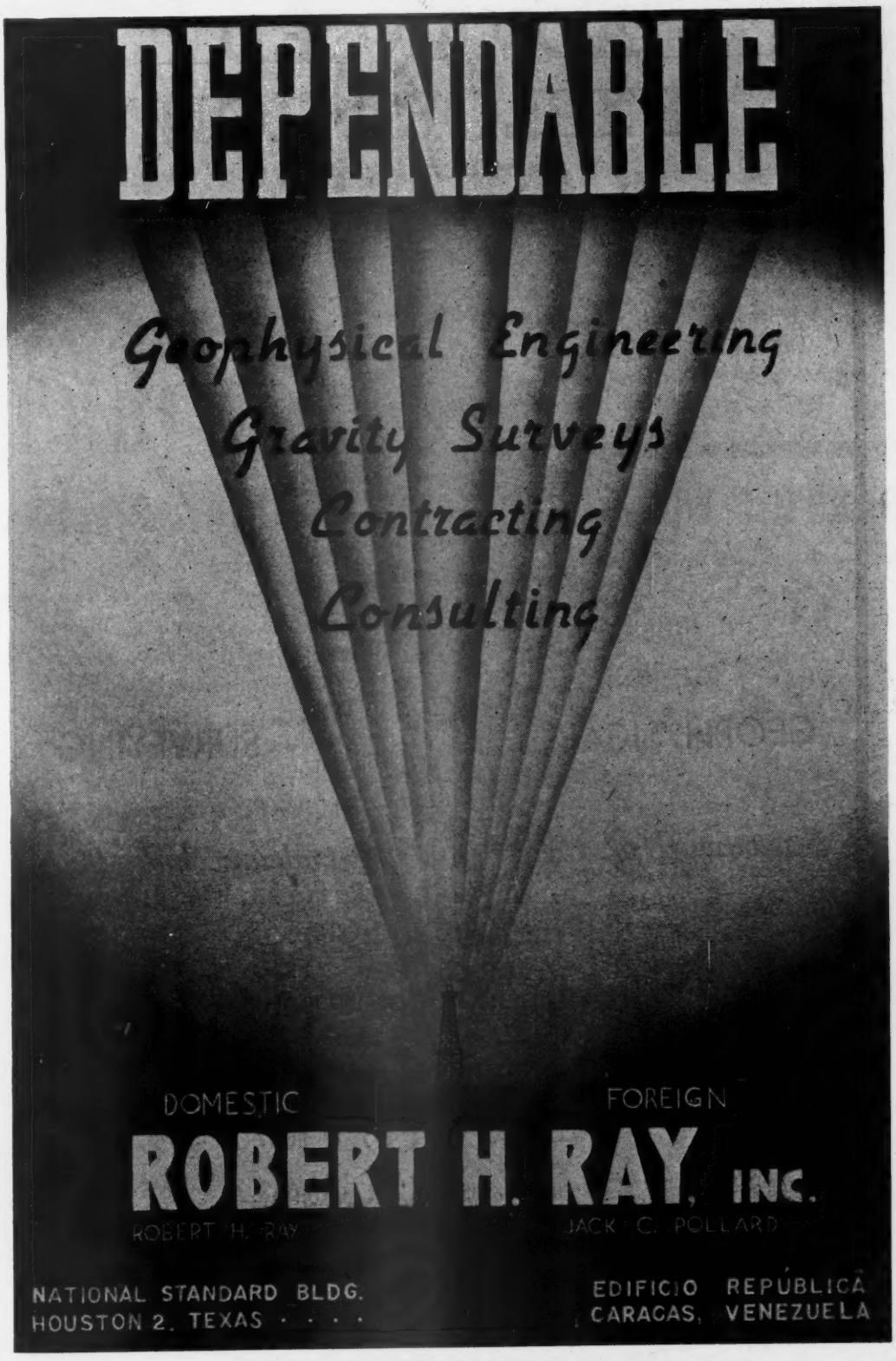

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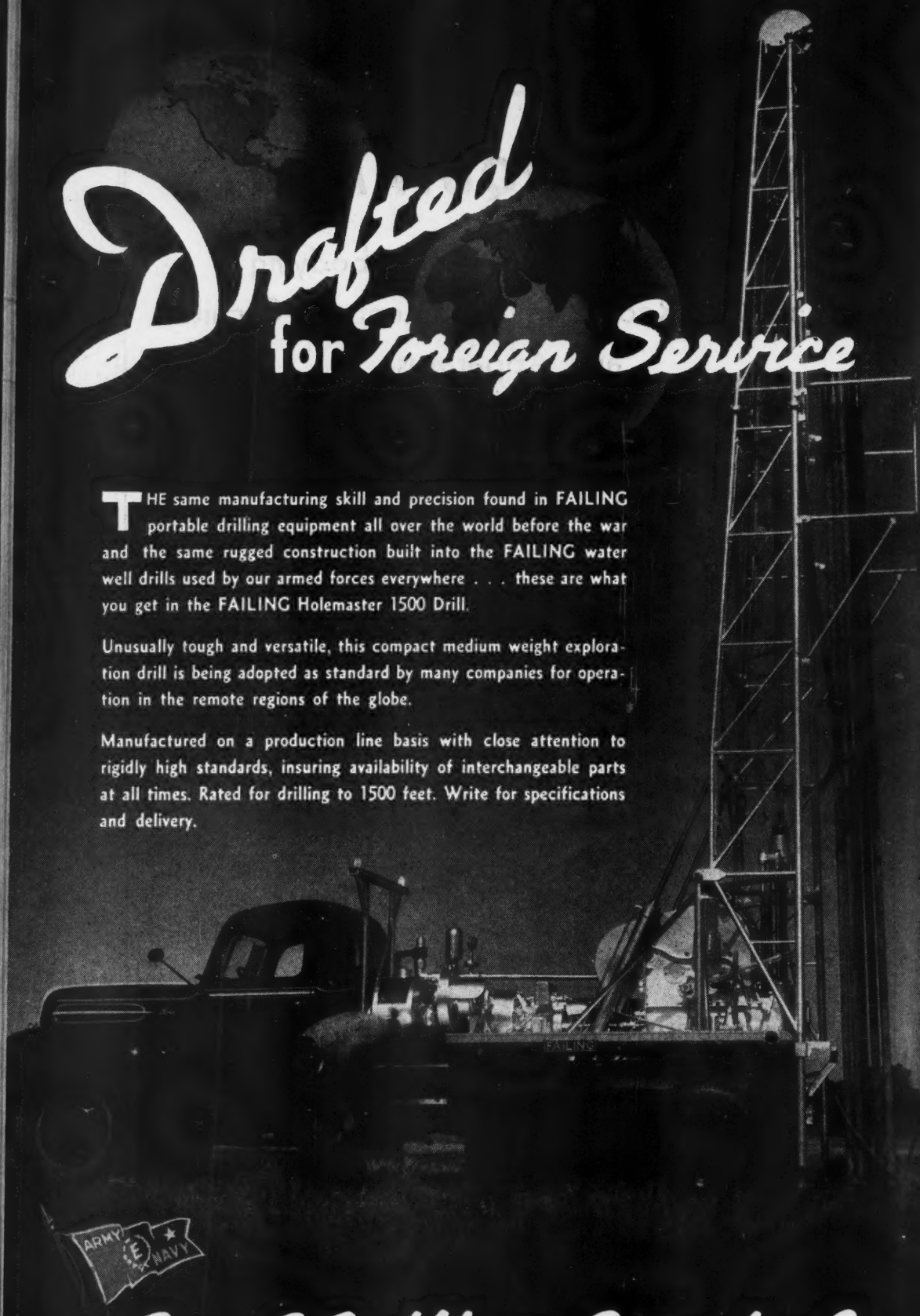

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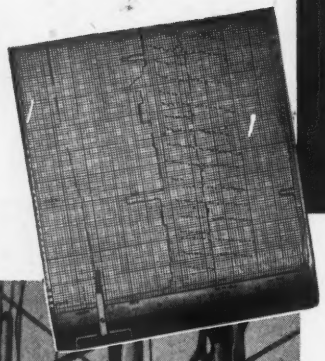

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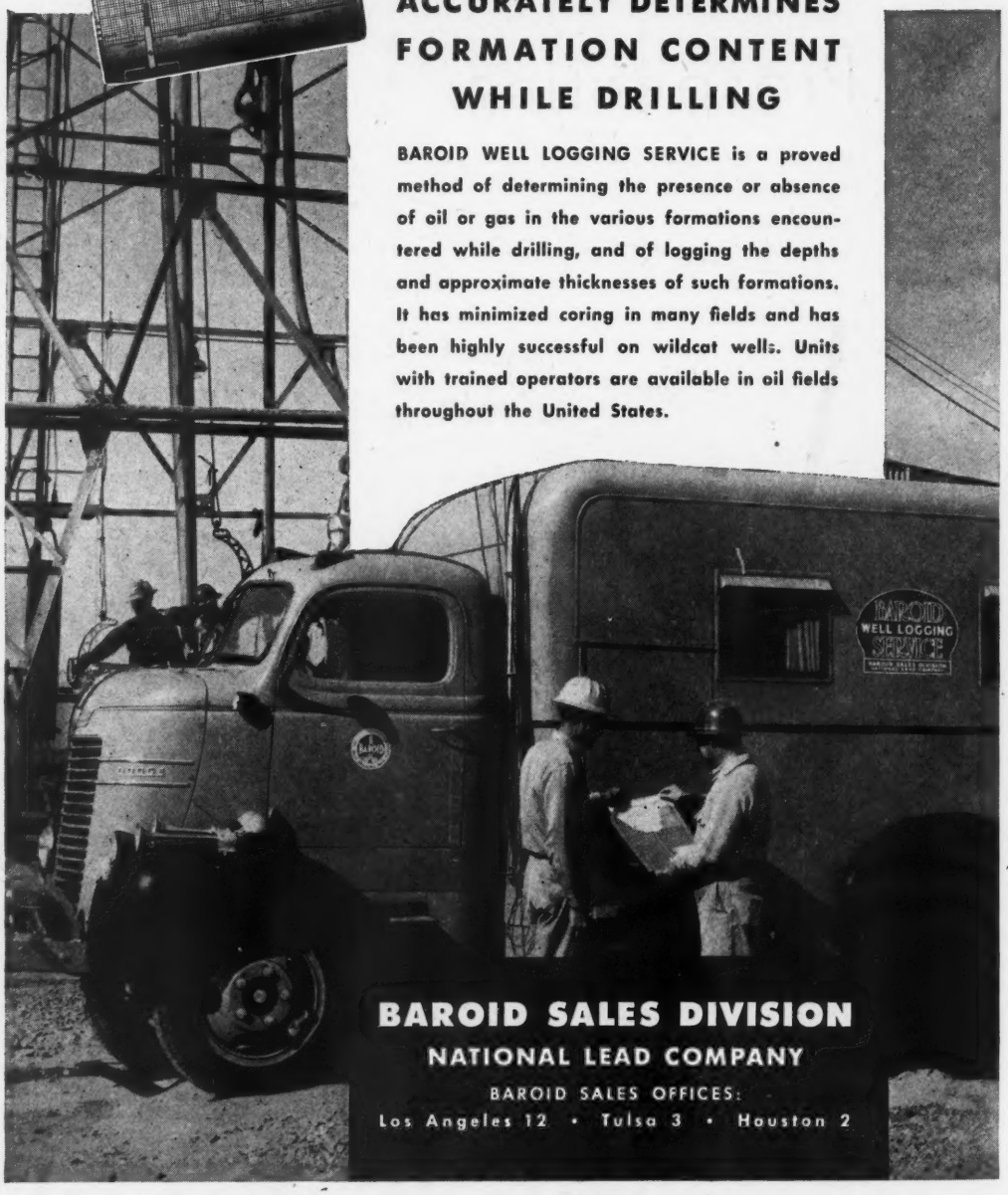

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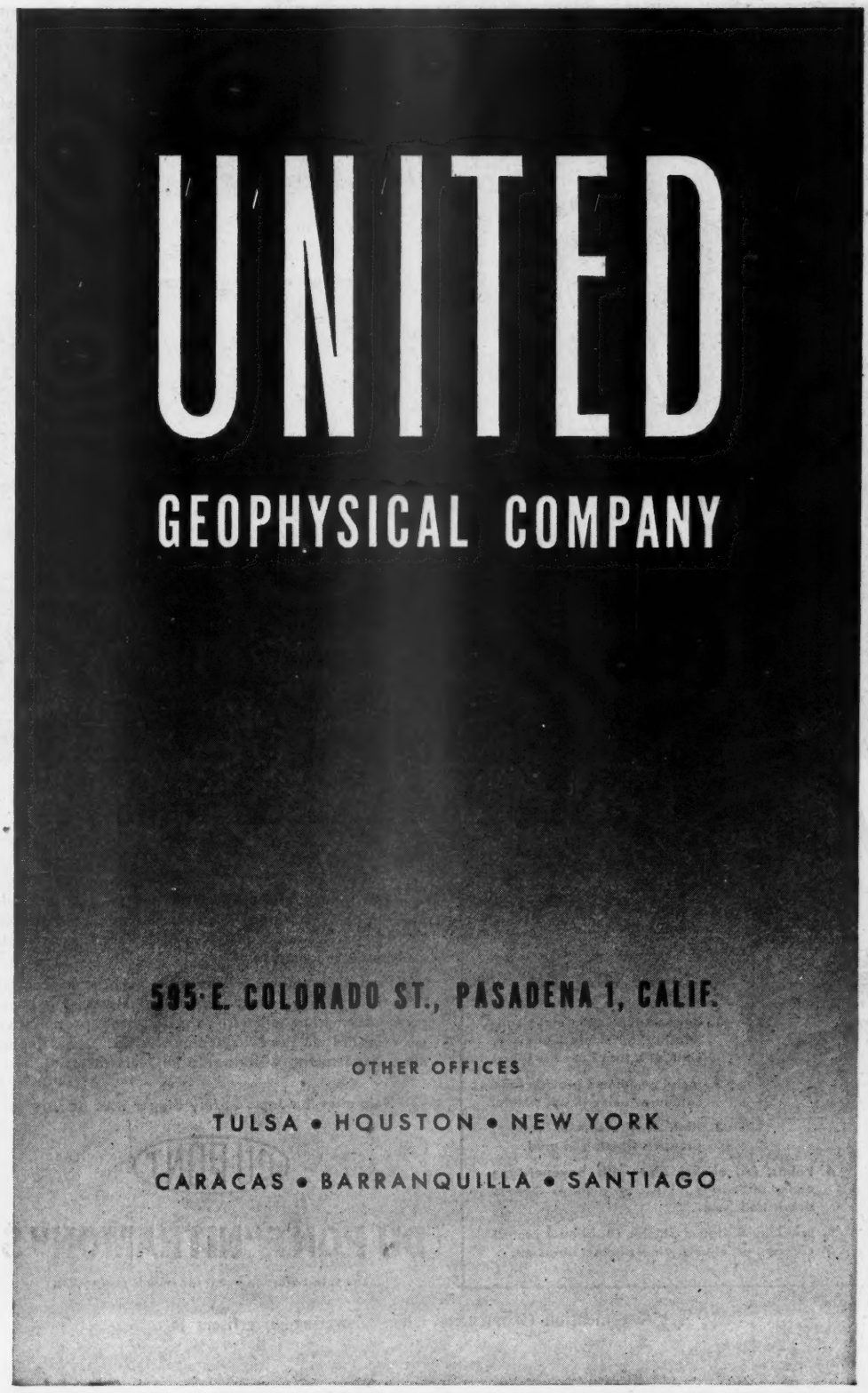
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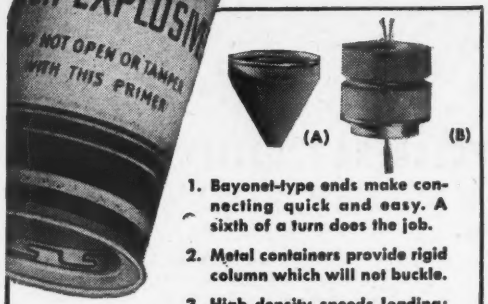
At left: New 4-inch "Nitramon" S and Primer. Note size of rocks encountered in drill hole.

...speeds loading seismic charges!



1. Bayonet-type ends make connecting quick and easy. A sixth of a turn does the job.
2. Metal containers provide rigid column which will not buckle.
3. High density speeds loading; prevents floating in mud.
4. Points, (A, above) also with bayonet-type ends, materially assist in getting charges down bad holes.
5. Specially designed shields (B, above) protect cap against shock; wires against abrasion.

Wherever tough loading conditions are encountered, use 4-inch "Nitramon" S. This new, large-diameter "Nitramon" S has been developed to handle such work and take it in its stride.

4-inch "Nitramon" S offers the highest concentration of explosive energy per foot of charge. For complete information, talk with your Du Pont representative or write E. I. du Pont de Nemours & Co. (Inc.), Explosives Department, Wilmington 98, Delaware.

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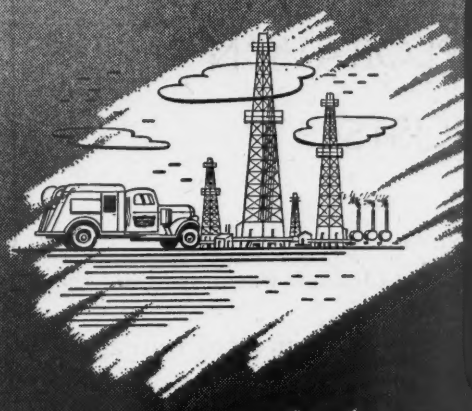

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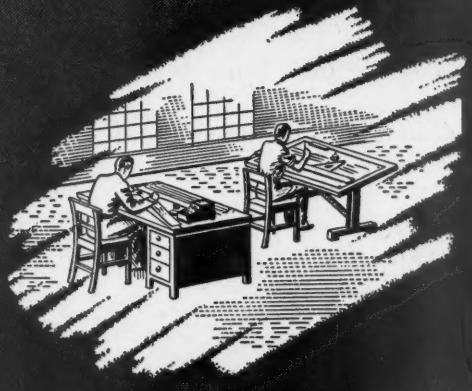

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SOCIETY OF EXPLORATION GEOPHYSICISTS

Announcement is made of the appointment of a new Business Manager by the Society to succeed J. F. Gallie, whose duties have forced his resignation. Editorial matters, as heretofore, will be handled by Dr. L. L. Nettleton, P. O. Box 2038, Pittsburgh 30, Pennsylvania. All other correspondence should be addressed to the attention of

E. STILES, BUSINESS MANAGER
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